A Study of PennDOT-Approved Specifications and Materials Used in Concrete and Asphalt Projects in District 4

FINAL REPORT

June 22, 2021

By: Farshad Rajabipour (PI), Mansour Solaimanian (co-PI), Jinyoung Yoon (Post-doctoral Researcher)

The Pennsylvania State University

COMMONWEALTH OF PENNSYLVANIA
DEPARTMENT OF TRANSPORTATION

CONTRACT # 4400015622/511601
WORK ORDER # PSU 015

Technical Report Documentation Page

1. Report No.	2. Government Accession No.	3. Recipient's Catalog No.
FHWA-PA-2021-003-PSU WO 015		

4. Title and Subtitle A Study of PennDOT-Approved Specifications and Materials Used in Concrete and Asphalt Projects in District 4	**5. Report Date** June 22, 2021 **6. Performing Organization Code**
7. Author(s) **Farshad Rajabipour, Mansour Solaimanian, Jinyoung Yoon**	**8. Performing Organization Report No.** LTI 2021-09
9. Performing Organization Name and Address The Pennsylvania State University University Park, PA, 16802	**10. Work Unit No. (TRAIS)** **11. Contract or Grant No.** 4400015622/511601, Work Order PSU 015
12. Sponsoring Agency Name and Address The Pennsylvania Department of Transportation Bureau of Planning and Research Commonwealth Keystone Building 400 North Street, 6th Floor Harrisburg, PA 17120-0064	**13. Type of Report and Period Covered** Final Report, 12/22/2020 – 6/22/2021 **14. Sponsoring Agency Code**

15. Supplementary Notes

Brian Wall, of the Bureau of Planning and Research, served as the project technical advisor. Heather Sorce, of the Bureau of Planning and Research, served as the project contract manager.

16. Abstract

In this project, a comprehensive evaluation of the current and recent PennDOT specifications relevant to concrete flatwork (primarily sidewalks) and asphalt pavements was performed. This evaluation was triggered by a number of recent premature deteriorations in the form of deicing salt scaling of concrete sidewalks and thermal segregation of asphalt pavements on several state roads within PennDOT District 4. The causes of the observed distresses were identified based on a review of the construction documents and a site visit/inspection. The governing PennDOT specifications were compared with the relevant state-of-the-art research results from the literature, the national standards and specifications, as well as the specifications from six other state DOTs. Additionally, a review of the PennDOT-approved materials and additives used in concrete and asphalt projects in District 4 were performed. The project outputs include recommendations for improving PennDOT specifications as well as other technical recommendations to prevent the observed damage types in concrete and asphalt projects. Suggested methods for remedial actions and rehabilitation of the existing damage are also offered.

17. Key Words	18. Distribution Statement
Concrete sidewalk, concrete pavement, asphalt pavement, surface scaling, thermal segregation	No restrictions. This document is available from the National Technical Information Service, Springfield, VA 22161

19. Security Classif. (of this report)	20. Security Classif. (of this page)	21. No. of Pages	22. Price
Unclassified	Unclassified	180	**$47,231.68**

Form DOT F 1700.7 **(8-72)** **Reproduction of completed page authorized**

Disclaimer

The contents of this report reflect the views of the authors who are responsible for the facts and the accuracy of the data presented herein. The contents do not necessarily reflect the official views or policies of the Federal Highway Administration or the Commonwealth of Pennsylvania at the time of publication. This report does not constitute a standard, specification, or regulation.

Table of Contents

List of Tables

List of Figures

Acknowledgements

Funding for this project was provided by the Federal Highway Administration and the Pennsylvania Department of Transportation. The authors sincerely appreciate the technical and administrative support provided by the project's Technical Advisor, Mr. Brian Wall, and the Project/Contract Administrator, Ms. Heather Sorce. The feedback and assistance provided by other PennDOT personnel, specifically Mr. Robert McGowan (PennDOT District 4) and Mr. Joseph Robinson (PennDOT Bureau of Project Delivery) are acknowledged and appreciated. The authors also thank Mr. Jason Gutting and Mr. Kevin Kennedy of Michigan DOT, Mr. Curt Turgeon of Minnesota DOT, Mr. Todd Whittington of North Carolina DOT, Mr. Miles Garrison of Texas DOT, Ms. Angela Beyke of Virginia DOT, and Mr. Barry Paye of Wisconsin DOT for coordinating their DOT's response to the surveys conducted in this project. Finally, assistance from Mr. Michael Casper and other staff of the Larson Transportation Institute at Penn State is much appreciated.

Executive Summary

In this project, a team of Penn State researchers conducted a comprehensive evaluation of the current and recent PennDOT specifications relevant to concrete flatwork (primarily sidewalks) and asphalt pavements. This evaluation was triggered by the recent premature deterioration of concrete sidewalks in the City of Wilkes-Barre, PA and the segregation of asphalt pavements at SR1016 and SR2020 in the vicinity of the town of Olyphant, PA. The causes of the observed distresses were identified based on a review of the construction documents and a site visit/inspection. The governing PennDOT specifications were compared with the relevant state-of-the-art research results from the literature, the national standards and specifications, as well as the specifications from six other state DOTs (Michigan, Minnesota, North Carolina, Texas, Virginia, and Wisconsin). Additionally, a review of the PennDOT-approved materials and additives used in concrete and asphalt projects in District 4 was performed. Finally, recommendations for repairing the existing damaged structures in District 4 were offered.

Based on the findings and other information collected in this project, the following major conclusions are drawn:

- The following factors are the most likely causes of the observed surface scaling of concrete sidewalks on the Wilkes University campus: (a) concrete had excessive amount of slag cement; (b) concrete had excessive slump; (c) PennDOT Class A concrete, which was selected for construction of the sidewalks, is not an appropriate choice for concrete that is exposed to freezing-and-thawing and in continuous contact with moisture and exposed to deicing chemicals; and (d) concrete finishing and curing practices were likely inadequate.

- In comparison with states with similar or colder climates, PennDOT's current specifications for concrete sidewalks allow for a higher water to cementitious materials ratio (w/cm), a higher supplementary cementitious materials (SCM) content, and a higher slump. These factors increase the risk of surface damage in concrete flatwork.

- To improve the longevity of concrete pavements, in recent years PennDOT has significantly improved its specifications. This includes raising the quality requirements for Class AA concrete by reducing the allowable maximum w/cm and increasing the allowable minimum 28-day strength. PennDOT has also expanded the requirements for construction and curing, including limiting the allowable water evaporation rate, disallowing the use of steel or Fresno floats, and prohibiting the addition of water or monomolecular film to the concrete surface to assist in finishing. Similar mix design and construction requirements should be considered for concrete sidewalks.

- The likely cause of low to moderate levels of surface segregation in the studied asphalt pavements in District 4 is paving at low temperature and thermal segregation of the mix.

- Almost every state surveyed reported that cold weather asphalt paving is a challenge and can result in problems needing special attention. Measures taken by states for cold weather paving include insulated trucks, higher mix temperatures, thicker layers, and using warm-mix asphalt additives. Paver-mounted thermal imaging is used by two of the surveyed states and is recommended as a very useful tool to monitor the pavement temperature differences with respect to thermal segregation in cold weather paving.

- PennDOT specifications related to asphalt pavements have been improved significantly within the last 5 years. These include mandatory use of anti-stripping agent, use of fine Superpave asphalt mixtures, and application of tack coat. Also, there have been major changes in weather and seasonal limitations of asphalt paving to minimize problems associated with cold weather paving.

- PennDOT-approval procedures for inclusion of materials and additives under its bulletins as “pre-approved materials” or “pre-approved producers of concrete or bituminous materials” are in accordance with national standards and specifications such as ASTM and AASHTO. Provided that these approval procedures are carefully followed both for the initial certification as well as the annual quality control (QC) of the approved materials and producers, these approved materials should lead to producing high-quality concrete and asphalt mixtures.

Additionally, the Penn State team offers the following technical recommendations for consideration by PennDOT, including potential areas of improvement within the governing PennDOT specifications:

- Publication 408, Section 676: Cement Concrete Sidewalks:
  - 676.2: Replace “Class A Cement Concrete” with “Class AA Cement Concrete for Form Paving according to Table A of Section 501.2”
  - Add: “The maximum allowable slump is 5 inches.”
  - Add: “Do not use vibratory screeds when concrete target slump is over 3 inches.”
  - Add: “After floating and straightedge testing, any additional finishing of concrete surface must wait until after the bleeding has completed and the bleed water has evaporated or has been removed, and after the initial setting of concrete. Adding water to make finishing easier or reworking of bleed water into fresh concrete surface are not permitted. Excessive finishing or troweling of the concrete surface using Fresno and power trowel are not permitted.”
  - Add: “Curing must be commenced immediately after finishing. Care must be taken to make sure the exposed concrete surfaces never dry out. If curing is delayed for any reason, an intermediate monomolecular film curing agent must be applied to protect the surface.”

- Publication 408, Section 704:
  - Add: “For prevention of alkali-silica reaction (ASR), the dosage level of supplementary cementitious materials (SCM) beyond values prescribed in 704.1(g)2.b are not recommended as they may cause excessive retardation of setting and strength development of concrete at early ages. This can be critical in cool and cold weather construction. Plans to mitigate such retardation effects and ensure proper construction and curing of concrete containing SCM must be presented to the Department for approval.”

  - Add language to ensure that ACI-certified Flatwork Finishers or NRMCA-certified Exterior Flatwork Finishers are employed by the contractor to finish concrete projects, including concrete pavements and sidewalks.

- Using magnesium- and ammonium-based deicers and anti-icers should not be permitted for concrete pavements, bridge decks, sidewalks, and other horizontal surfaces.

- For repair of scaled sidewalks in District 4, it is recommended to remove the cracked and scaled surface (to a minimum of ½ inch depth from the surface), followed by application of a durable overlay. Proper methods for removal of unsound concrete, surface preparation of the substrate, and selection of proper overlay materials are discussed in Chapter 6.

- Balanced Mix Design and Performance Based Testing for Asphalt: These tools have gained considerable momentum in recent years and PennDOT is considering such specifications. It is recommended that PennDOT continue this effort expeditiously. Use of performance tests with pavement cores is especially important with cold paving, as the risk of pavement problems increases when the mix is placed at cold temperatures.

- Bond Strength Evaluation in Cold Weather Paving: Current PennDOT specifications do not require bond strength evaluation at the interface between layers. In case of cold weather paving, proper bonding becomes a more sensitive issue and it is recommended that in the case of paving in extended season, specifications include a section to require measuring the bond strength according to one of the existing established protocols for such measurements.

- Checking for Thermal Segregation: Frequent measurement of pavement mat temperature at different and random spots at the time of placement is recommended to ensure the uniformity of mat temperature and to ensure that thermal segregation is not occurring in the mix. In extended season paving, using an infrared (IR) temperature sensor bar behind the paver is a good practice. However, while making mat temperature measurements should be a mandatory part of specifications for extended season paving, use of IR temperature sensor bar for cold weather paving may remain as a recommendation rather than a requirement at this time.

- PennDOT follows PTM 751 (sand patch test) to identify segregation with a follow-up of pavement coring to determine changes in density, asphalt content, and gradation. Based on the results of the tests, if segregation is warranted, removal and replacement of the pavement is required. It is recommended that a tiered approach be applied to rank the level of segregation as none, low, intermediate, or high to guide the decision of the remedial action, which could be none, patching, or removing and replacing. This tiered approach could be developed based on laboratory performance test results.

The authors acknowledge that recommendations made in this report regarding changes in PennDOT specifications are subject to review and consideration by PennDOT for inclusion in specifications and final implementation. It is understood that specification changes are required to follow a normal process of review and discussion, including the clearance transmittal process. The final decision and responsibility for any revisions to specifications remains with PennDOT.

Chapter 1. Review of Documents Related to Concrete and Asphalt Projects in District 4

1.1 Introduction

This chapter provides analysis of documents and site observations related to concrete and asphalt projects in PennDOT District 4 that experienced premature deterioration. The chapter identifies the most likely sources and causes of distress in these projects along with the relevant PennDOT specifications, policies, and procedures that must be evaluated in the remaining tasks of the WO15 project.

This chapter is divided into two main sections. Section 1.2 summarizes the Penn State team's findings and opinions regarding the types and causes of deterioration of concrete sidewalks located at West South Street and South Franklin Street in Luzerne County, in the City of Wilkes-Barre, PA. Section 1.3 summarizes the research team's findings and opinions regarding the types and causes of deterioration of asphalt pavements of SR 1016 and SR 2020, in the vicinity of the town of Olyphant, PA. Each section also includes a summary of the data that were assembled based on reviewing the documents provided by PennDOT, information collected during a site visit on January 25, 2021, and other information referenced herein. The applicable PennDOT specifications are also listed.

1.2 Concrete Sidewalks

Background

The concrete sidewalks, which are the subject of this study, were placed during the period from June to September 2017. The project owner was Wilkes University (WU) of the Commonwealth of Pennsylvania Luzerne County. The concrete was supplied by Coon Industries, Inc., which is a PennDOT-approved concrete plant according to Bulletin 42. The project contractor was Latona Trucking, Inc. According to the contract dated November 30, 2016, between WU and Latona, PennDOT Publication 408/2016-IE (initial edition) was the governing project specifications.

During a site visit on January 25, 2021, the Penn State team observed surface scaling of the concrete sidewalk on West South Street. Surface scaling is the deterioration of the top layer (1/8 to ¼ inch deep) of the surface of the concrete sidewalk (**Figures 1–3**). Scaling was observed on all sidewalk panels with varying degrees of severity. The degree of scaling could be classified as moderate to severe (ratings 3 to 4) according to the ASTM C672-12 standard. Scaling debris was present on the sidewalks, indicating that the scaling deterioration was likely ongoing.

Figure 1. Moderate to severe scaling of the concrete sidewalk. The presence of scaling debris suggests that scaling deteriorations are ongoing.

Figure 2. Moderate to severe scaling of the concrete sidewalk. The joint seal has remained in place, preventing penetration of the joints by scaling debris and other incompressible materials.

Figure 3. Moderate to severe scaling of the concrete sidewalk

Documents reviewed

ECMS 104323_Part_1 (Bates stamped PSU-WO15-LC-1 to 44)
ECMS 104323_Part_2 (Bates stamped PSU-WO15-LC-45 to 88)
ECMS 104323_Part_3 (Bates stamped PSU-WO15-LC-89 to 91)
Wilkes University Concrete Information (Bates stamped PSU-WO15-LC-92 to 270)
Email from Mr. Robert McGowan to District 4 concrete producers, dated 6-29-2018 (Bates stamped PSU-WO15-LC-271)
Email from Mr. Robert McGowan to Penn State, dated 1-25-2021 (Bates stamped PSU-WO15-LC-272)
Wilkes Sidewalk QC/QA Results (Bates stamped PSU-WO15-LC-273 to 301)
Photos of the sidewalks and cores provided by Mr. Robert McGowan to Penn State via email, dated 2-26-2021 (Bates stamped PSU-WO15-LC-302 to 304)
NRMCA Best Practices for Exterior Finishing (Bates stamped PSU-WO15-LC-305 to 336)
Reducing Scaling of Concrete Surfaces - A PennDOT STIC Initiative (Bates stamped PSU-WO15-LC-337 to 376)

Information obtained by review of the documents

The Penn State team did not have access to design drawings for this project. But based on the available ECMS information (Bates stamped PSU-WO89-LC-91 [1]), it appears that a 5-inch-thick plain cement concrete sidewalk was to be placed except for the sidewalk at driveway entrances, which was supposed to be 6 inches thick. A QC photo by Geo-Science Engineering (**Figure 4**, Bates stamped PSU-WO15-LC-289 [2]) shows that a wire mesh was placed at a driveway entrance. The wire mesh appears to be black steel without coating. The rebar size, spacing, and cover thickness are unknown.

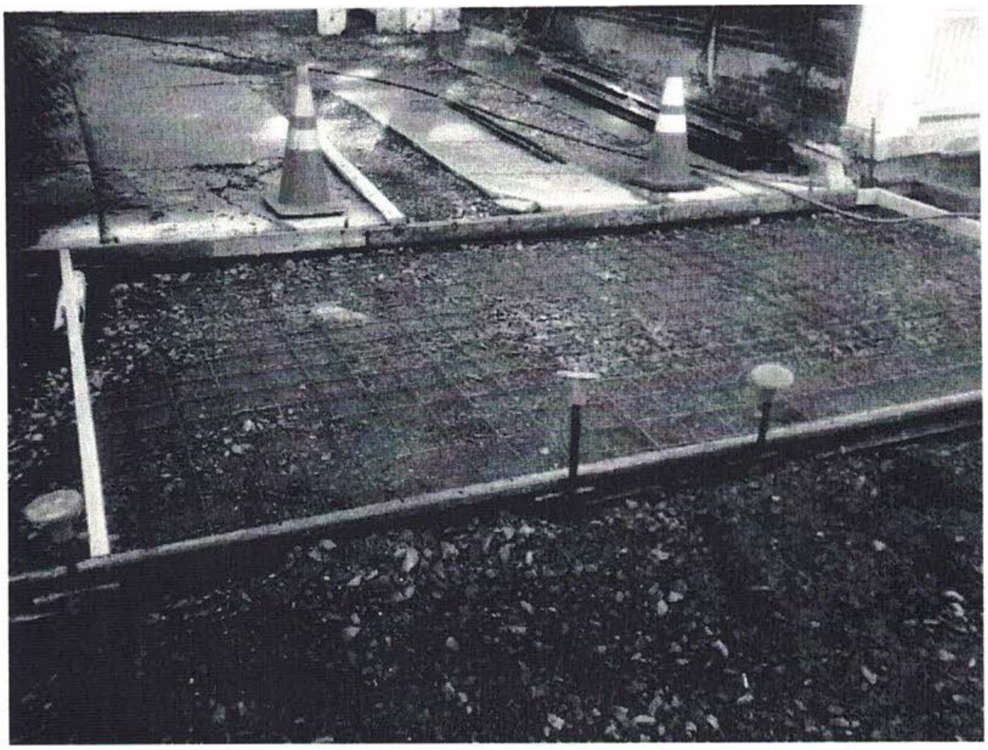


Figure 4. Wire mesh placed for sidewalk at a driveway entrance (photo from [2])

According to the approved concrete mix design (Bates stamped PSU-WO15-LC-18 [1]), PennDOT Class A concrete containing 40% mass of ground granulated blast furnace slag (GGBFS) replacing an equal mass of portland cement was used for the sidewalk project. Portland cement was a Type I/II supplied by Buzzi Unicem in Stockertown, PA. GGBFS was Grade 100 from Essroc (Heidelberg Cement) in Camden, NJ. Coarse aggregate was Class A57 from Pennsy Supply Inc. North in Pittston, PA. Fine aggregate was Class A from Barletta Materials. Both aggregates are PennDOT approved and included in PennDOT Bulletin 14. The approved 7-day and 28-day compressive strengths of Class A concrete (based on a w/cm = 0.50 design) were 3,210 psi and 5,474 psi, respectively. According to the approved QC plan (Bates stamped PSU-WO15-LC-13 to 17 [1]), the target concrete slump was in the range of 3 to 6 inches, the concrete temperature specification limits were 50 °F to 90 °F, and the concrete fresh air content specification limits were 4.5% to 7.5%.

According to the Batcher Mix Slips and Concrete Delivery Tickets provided in the Wilkes University Concrete Information (Bates stamped PSU-WO15-LC-92 to 270 [1]), Class A concrete with 40% GGBFS as cement replacement was delivered by Coon and placed by Latona during the period from June 7 to September 13, 2017. The majority of this concrete had a w/cm=0.47, although occasionally w/cm = 0.45, 0.46, or 0.48 were used. The cementitious materials (cement + GGBFS) factor was 580 to 611 lb/yd^3. QC data included on concrete delivery tickets indicate that the concrete slump was in the range of 3.5 to 6.0 inches, the fresh air content of concrete was in the range of 4.6% to 6.8%, and the temperature of concrete at delivery was in the range of 68 °F to 87 °F. All three measured parameters (slump, air, and temperature) were in compliance with the approved QC plan. It is noted that on one occasion on June 14, 2017, a slump of 7.0 inches and a fresh air content of 8.0% were reported by the PennDOT plant inspector (PSU-WO15-LC-132). The concrete delivery tickets did not report any water addition to concrete before discharge from trucks. Compressive strength QC testing was performed by Geo-Science Engineering Co., Inc. and the QA testing was performed by

PennDOT. The results are reported in Wilkes Sidewalk QC Results (Bates stamped PSU-WO15-LC-295 to 301 [2]), showing the 7-day compressive strength to be in the range of 2,646 psi to 3,572 psi, which at times was below the approved 7-day compressive strength of 3,210 psi and even below the PennDOT Publication 408 Section 704.1(b) limit of 2,750 psi. The measured 28-day compressive strength of concrete was in the range of 3,864 psi to 5,455 psi, which at times was below the approved 28-day compressive strength of 5,474 psi but above 3,300 psi set by Publication 408 Section 704.1(b).

According to PennDOT Publication 408/2016-IE, Section 676 – Cement Concrete Sidewalks, Class A cement concrete according to Section 704 must be used for sidewalk construction. Such concrete must have a cement factor in the range of 564 to 752 lb/yd^3, a maximum w/cm of 0.50, and a minimum mix design compressive strength of 2,750 psi and 3,300 psi at 7 and 28 days, respectively. Special Provision a00046 was applicable to this project, which specified changes to sections 701, 704, and 724 of the specifications (Bates stamped PSU-WO15-LC-43 to 55 [1]). Most significantly, Section 704.1(g) Mix Designs Using Potentially Reactive Aggregates was updated to comply with the AASHTO R 80 document. According to information from PennDOT Bulletin 14, the coarse aggregates in the concrete supplied by Coon were moderately reactive (Class R1) while the fine aggregate was non-reactive (Class R0). According to the updated specifications in Special Provision a00046, the concrete must have contained a minimum 25% by mass of GGBFS as a cement replacement to mitigate ASR. The concrete supplied by Coon contained 40% GGBFS.

Unfortunately, very little documented information is available about the methods of construction, finishing, and curing of the concrete sidewalks. According to email from Mr. Robert McGowan, dated 1-25-2021 (Bates stamped PSU-WO15-LC-272 [3], the sidewalks were screeded using a power screed and cured using a white spray cure (curing compound). The brand name, application dosage, and time of application of the curing compound are unknown. According to Mr. McGowan, the sidewalks were de-iced using rock salt starting from the first winter after construction.

PennDOT Publication 408/2016-IE, Section 676 asks for a light broom finish but otherwise refers to Section 1001.3 for construction, finishing, and curing of sidewalks. The latter prevents adding water to concrete in the field, unless authorized in writing by the District Executive. The authors did not find any further information about appropriate methods of finishing sidewalks within this specifications section. Section 1001.3(p) allows for curing by liquid membrane-forming curing compound by applying two coats at a minimum dosage of 1 gallon per 300 ft^2 of concrete surface per coat. The curing compound must be applied to "*unformed surfaces immediately after finishing operations have been completed and after the surface film of water has disappeared.*" Alternatively, water curing for a minimum of 7 days is allowed.

Scaling deteriorations were observed in concrete in early 2018 (i.e., less than one year in service). A set of two cylindrical cores ($3\frac{5}{8}$ inch diameter) were collected in June 2018 and sent for petrographic examination that was performed by PennDOT Laboratory Testing Service (LTS) in Harrisburg, PA. The petrographer observed that the cores had three distinct horizons, with the first horizon being within the uppermost $\frac{1}{8}$ inch of each core and having a very light yellowish-brown color (Bates stamped PSU-WO15-LC-23 to 29 [1]). The second horizon continued to a depth of 2¾ inches from the top surface of the cores and had a slightly darker warm yellowish-brown color. A microscopic examination of the cores led the petrographer to conclude "*The variation in the paste quality in the uppermost paste horizon suggests that the paste cured with a higher w/cm, which is different from the concrete in the rest of the core,* *which had a lower w/cm.*" The cores contained one or more vertical cracks (likely caused by drying shrinkage) extending up to $2^1/_8$ inches from the core surface. The report further states "***The w/cm ratio of the uppermost paste horizon is higher than the rest of the core. The paste quality suggests that water was incorporated into the top surface of the core during the finishing of the concrete****. The excess water and finishing process create weakened paste and has the potential to remove and redistribute some of the entrained air within the uppermost lightly colored paste horizon. The weakened concrete with lowered entrained air is then more susceptible to freeze thaw delamination [i.e., scaling].*"

Another set of two cores were submitted by Mr. Jim Casilio of the Pennsylvania Aggregate and Concrete Association (PACA) to American Engineering Testing, Inc. (AET) in Saint Paul, MN, for petrographic examination. AET's analysis (Bates stamped PSU-WO15-LC-70 to 83 [1]) concluded the cause of concrete scaling to be "**inadequate curing**." Their report states: "*No residual evidence of use of a membrane-forming curing agent was observed on either sample. The amount and depth of drying shrinkage microcracks present in both concrete samples suggest that the concretes experienced a rapid loss of moisture at an early age.*" "*We expect deterioration of the carbonated surface paste [up to $^3/_8$ of an inch from surface of the sidewalk] to continue if the concrete is subject to cyclic freeze-thaw conditions when saturated.*" An air void analysis was also performed by AET, suggesting that the analyzed bulk concrete had adequate air content in the range of 5.8% to 6.5% and proper air void spacing factor in the range of 0.004 to 0.006 inches.

<u>Opinion regarding the causes of premature deterioration of concrete sidewalk</u>
In the professional opinion of the authors, the following factors contributed to the observed scaling of the concrete sidewalks. These are presented chronologically but not in the order of significance:

- PennDOT Class A concrete is not an appropriate choice for concrete that is exposed to freezing and thawing, is in continuous contact with moisture, and is exposed to deicing chemicals. According to ACI 318-19 code, Section 19.3.1, such concrete is classified as having "Very severe – Class F3" exposure with respect to freezing and thawing and "Severe – Class C2" exposure with respect to corrosion of reinforcing steel. According to this code, to ensure freeze-thaw durability in such an environment, unreinforced concrete must have a minimum 28-day compressive strength of 4,500 psi and a maximum w/c ratio of 0.45. Reinforced concrete must have a minimum 28-day compressive strength of 5,000 psi and a maximum water to cement (w/c) mass ratio of 0.40 to sufficiently protect the rebar against corrosion.

- Concrete containing GGBFS in amounts exceeding 25% of the total cementitious materials is known to be more susceptible to scaling [4,5]. According to PennDOT Publication 408 Section 704.1 (g), 25% GGBFS was sufficient to mitigate ASR in this concrete. The choice of 40% slag was unnecessary and contributed to a higher risk of scaling of concrete. An email from Mr. Robert McGowan to District 4 concrete producers, dated 6-29-2018 (Bates stamped PSU-WO15-LC-271 [6]) requested "*that all District 4 concrete producers submit a separate Class A and AA mix design with the S2/Sidewalk designation. Any fly ash mix is acceptable, however, if using slag, the percentage should not exceed 25%.*"

- The concrete had excessive slump. Concrete with higher slump is usually easier to place and work with during construction. But high slump can result in segregation of aggregates and excessive bleeding of concrete. Bleeding or bleed water refers to formation of a water layer on the horizontal surface of newly placed concrete. Among concrete ingredients, water has a lower density than aggregates and cement. As a result of gravity force, water naturally moves up and accumulates at the horizontal surface of concrete. Generally, the higher the concrete slump, the higher the bleeding. Excessive bleeding weakens the concrete surface and makes it prone to cracking and scaling. It can also interfere with setting and hardening of concrete, especially at cooler air temperatures, and delays final finishing. ACI document 211.1 Section 6.3 recommends that slump for pavements and slabs be in the range of 1 to 3 inches [7]. NRMCA Best Practices for Exterior Flatwork Finishing (Bates stamped PSU-WO15-LC-305 to 336 [8]) states: "*Slump that exceeds 5 inches may be easier to place but should never be used for slabs unless the slump is achieved using a high range water reducer. High slump concrete without high range water reducers can have excessive and prolonged bleeding, lower strength, longer set times, and a higher likelihood for scaling.*"

- According to the petrographic examination, there is evidence that concrete was not finished and cured properly. The observed higher w/cm at the surface of concrete "*suggests that water was incorporated into the top surface of the core during the finishing of the concrete*" (Bates stamped PSU-WO15-LC-23 to 29 [1]). This may be due to reworking of the bleed water into the surface. AET's petrographic analysis (Bates stamped PSU-WO15-LC-70 to 83 [1]) concluded the cause of concrete scaling to be "inadequate curing," stating that "*No residual evidence of use of a membrane-forming curing agent was observed on either sample. The amount and depth of drying shrinkage microcracks present in both concrete samples suggest that the concretes experienced a rapid loss of moisture at an early age.*" Inadequate finishing and curing of concrete slab on grade causes formation of a weak and high porosity surface layer that is prone to scaling and cracking.

In the authors' opinion, based on the available evidence, the concrete sidewalk will continue to scale. Additionally, there is potential for premature corrosion of uncoated reinforcing steel where it was used (at driveway entrance sections). This is because of a higher than appropriate w/cm (> 0.45) for concrete that is exposed to moisture and deicing salts, and the presence of drying shrinkage vertical cracks that accelerate penetration of deicing salts to the level of rebar. These conditions foster an elevated risk of steel corrosion.

1.3 Asphalt Pavements

Background

The resurfacing of approximately 18.26 miles of asphalt roadways was conducted on state routes SR 307 (1.44 miles), SR 0435 (7.96 miles), SR 1016 (2.16 miles), SR 2020 (1.80 miles), and SR 3011 (3.99 miles). The mix was warm mix asphalt placed during the project period of April to December 2019. The asphalt mixture was supplied by New Enterprise Stone & Lime Co., which is a PennDOT-approved plant according to Bulletin 41. PennDOT Publication 408/2016-5 (fifth edition) was the governing project specifications. The applicable sections of Spec 408 are sections 409 and 411. Only two technical changes were applied to these two sections during the life of the 2016 edition. Change No. 2 added the use of fine mixes with nominal maximum aggregate size of 4.75 mm to section 409, and Change No. 3 made use of antistripping agents mandatory as specified under Section 411.

The state roads 1016 and 2020 were the only projects considered for the following review and analysis, as these were the two projects reported to have manifested surface distresses. In addition, the mix design used on both roads 1016 and 2020 comes from the same job mix formula (JMF). At the time of this writing, it is not clear if the other roads listed above had the same JMF.

The research team visited SR 1016 in Lackawanna County in the morning of January 25, 2021 for visual assessment of the road condition. The section of the road visited was within Segment 10, from offset 1800 to 2200. Mr. Robert McGowan of PennDOT accompanied the team at this site visit. At the time of this visit, the pavement was roughly 15 months old from the time of placement. The 1.5-inch-thick wearing course was placed in late October/early November 2019 after milling 1.5 inches of the surface. Previous rehabilitation to the road was conducted in 2005 where the surface was milled to a depth of 1.5 inches and was surfaced with 1.5 inches of ID-2 mix. The research team did not visit SR 2020 due to time constraints and communication with PennDOT indicates that the condition of this road resembles that of SR 1016.

The assessment of the pavement condition took place visually and from the roadside (**Figures 5–8**). The pavement surface appeared free of cracking. Visual inspection indicated minimal rutting of the pavement mat. Rutting was not measured directly due to inaccessibility of the roadway and lack of traffic control. The surveyed section of the road indicated a low to moderate level of surface segregation. This assessment of low to moderate level segregation is subjective and purely based on visual observation of the surface condition. The width of the lane in each direction was measured at 12 ft. The surface mix in parts appeared lacking fines and was clearly coarser as compared to the rest of the mat. The area of apparent segregation was measured to be within 2 to 8 ft from the pavement edge. While the segregation seems to extend through a long stretch of the road, there were only specific areas with a moderate level of segregation, and most of the pavement exhibited a low level of mix segregation. Again, this ranking of low to moderate level of segregation was purely based on visual observation with no direct measurement.

Figure 5. Moderate level of segregated mat on the eastbound lane of SR 1016 – View 1

Figure 6. Moderate level of segregated mat on the eastbound lane of SR 1016 – View 1

Figure 7. Closeup of the segregation mat on the eastbound lane of SR 1016 – View 1

Figure 8. Closeup of the segregated mat on the eastbound lane of SR 1016 – View 2

<u>Documents reviewed</u>
Exhibit A: ECMS Bid Package
Exhibit B: Project Schedule
Exhibit C: Project Schedule Classic WBS Layout
Exhibit D: Bid Package: Material Bids

Exhibit E: Drawings for Construction
Exhibit F: Proposal Report
Exhibit G: Minimum Quality Control Plan for Field Bituminous Paving Operation
Exhibit H: Non-Vibratory Rolling Request September 9th
Exhibit I: Non-Vibratory Rolling Request October 4th
Exhibit J: Rolling Pattern Request-Drinker Street
Exhibit K: Late Season Paving Request
Exhibit L: Minimum Extended-Season Paving Plan
Exhibit M: Testing Reports
Exhibit N: Late Season Paving Remedial Action Required Remove and Replace
Exhibit O: SR 2020 Latent Defects Remove and Replace
Exhibit P: Spearin Doctrine Summary
Exhibit Q: ECMS Authorization for Contract Work
Exhibit R: Weather Observations from Wilkes-Barre/Scranton Airport
Exhibit S: Economic Waste Doctrine
JMF_W95222E2: Job mix formula report

Information obtained by review of the documents

According to the job mix formula report [9], the information of the warm-mix asphalt can be identified. The warm-mix asphalt was supplied by New Enterprise Stone & Lime Co. Coarse aggregate was Class A8 from White Haven Red Rock Sales in Plains, PA. Fine aggregate was Class B3 from New Enterprise Stone & Lime Co. in Laflin, PA. Both aggregates are PennDOT approved and included in PennDOT Bulletin 14. Reclaimed asphalt pavement was also from New Enterprise Stone & Lime Co. in Laflin, PA. The virgin asphalt binder was Performance Grade (PG) 64-22. The coarse aggregate is 100 crushed with an ignition correction factor of 0.0 for material passing the #200 sieve, an indication of high-quality aggregate. Both the dry strength and tensile strength ratios significantly exceed the minimum threshold values of 65 psi and 0.80, respectively, as required in PennDOT Bulletin 27. It should be noted that the date of TSR testing is reported as 2/18/15, about four and half years before placement of the mix. A summary of mix characteristics is presented below:

- Superpave 9.5-mm
- 20% reclaimed asphalt pavement
- Design gyrations: 75
- Aggregate skid resistance level: E
- Virgin binder: PG 64-22 applied at 4.5% content
- Total binder content: 5.8%
- Dry Indirect Tensile Strength: 97.4 psi
- Tensile Strength Ratio (TSR): 0.98

Review was made of available quality acceptance data for the SR 1016 and SR 2020. The data were limited to three construction lots for mixture acceptance. The summary of data as extracted from Exhibit M [10] is presented in **Table 1**. The weather data were extracted from Exhibit R [11].

Table 1. Summary of quality acceptance data for SR 1016 and SR 2020

S.R.	Placement Date	Air Temperature (°F)			# of Sublots	Percent Within Limits (PWL)				
		High	Avg	Low		AC	-#200	-#4	-#8	Density
1016	10/30/19 to 11/05/19	50 to 63	40.1 to 67.6	30 to 57	7	94	100	90	100	23
2020	10/12/19	61	52.9	44	3	100	100	100	100	100
2020	10/29/19	61	56.1	54	3	70	100	24	100	100

The mix and density acceptance data from single lot of SR 1016 indicates low density for this lot. The asphalt mix of this lot was placed during three days: 10/30, 11/04, and 11/05/2019. Among the three days, the lowest temperatures belong to 11/04 and that is when the lowest densities of the mix are observed in the corresponding sublots. On 11/04/2019, the reported high, average, and low air temperatures were 53 °F, 44 °F, and 30 °F, respectively.

The section of PennDOT Publication 408 that applies to this project is Section 411: Superpave Mixture Design, Standard, and RPS Construction of Plant-Mixed WMA Courses. Except specific subsections applicable to WMA, Section 41 follows requirements established in Section 409: Superpave Mixture Design, Standard, and RPS Construction of Plant-Mixed HMA Courses. One of the sections applies to extended season paving, which allows extension of paving beyond the regular season, which ends on October 31. This extension is allowed through November 20 upon approval. Both projects 1016 and 2020 were placed within this established timeframe, with part of the mix for SR 1016 placed within the approved extended season period. Section 409 does not allow placement of the mix when the air or surface temperature is 40 °F or lower or when the pavement surface is wet. Hourly data of temperature is needed to determine if the air temperature was below 40 °F at the time of paving for those dates when the temperature records indicate a low temperature below 40 °F. Finally, Section 409 requires the mixtures to be hauled in tightly sealed vehicles with insulation on all sides of the truck body, a double-walled truck body, or a heated truck body when the air temperature is below 50 °F from October 1 to April 30. Such information is needed (but was not available), since air temperature during several days of paving was below 50 °F. It must also be noted that, as indicated in Exhibits H [12] and I [13], due to poor condition of old cast-iron water pipes, the compaction rolling took place in static mode. As provided in PennDOT Publication 408/2016 section 409.3(i), the adequate compaction is required to achieve the density acceptance. Combination of cold temperature and static rolling may have contributed to low density for this lot.

The two construction lots of SR 2020 for which mix and density acceptance data are available indicated satisfactory tolerance on density and mix parameters. While the temperature on the two days when this mix was placed was cold (10/12 and 10/29/2019), it was significantly higher than the temperature on the days when the mix of SR 1016 was placed. A point worthy of consideration is the amount of material passing the #4 sieve. The percent within limits (PWL) for this material was only 24 percent. A close analysis of data indicated that the material passing the #4 sieve was consistently lower than the JMF reported value (66%), even though most of the time it was within range. The overall pay factor is determined based on density, asphalt content, material passing the #200 sieve, and material passing the primary control sieve (in this case, #8 sieve). The material passing the #4 sieve does not appear in determination of the pay factor but is an important sieve to consider when performing a forensic analysis of an asphalt mix. Finally, it must be noted that, as indicated in Exhibit J [14], mix acceptance for SR 2020 was based on the optimum rolling pattern due to poor subgrade condition.

Opinion regarding the causes of premature deterioration of asphalt pavement
A common problem in asphalt pavements, when paving occurs in cold weather, is attributed to thermal segregation. This phenomenon refers to nonuniform distribution of temperature across the mat. Thermal segregation becomes problematic when temperature difference within the mat becomes large (> 20F), resulting in cold spots. These colder parts of the mat may not receive adequate compaction. Sometimes, they create a thin crust not bonding to the rest of the mat, resulting in separation from the rest of the mat and raveling when exposed to traffic. Thermal segregation can also interfere with consistent flow and constant head of material at the spreading augers, which can lead to the mix segregation during the paving operations.

The reason thermal segregation becomes a more serious issue in cold weather is mainly due to more rapid heat loss. Long hauling distances or inefficiency in insulation and maintaining the temperature can aggravate the problem. It is because of the significant impact of maintaining a uniform temperature that Section 409.3(d) of the specifications puts specific requirements on the hauling equipment when the air temperature is below 50 °F. There is no information from the reviewed documents regarding hauling equipment and mix temperature to determine with a high degree of certainly that the temperature of the mix has been the factor causing the observed problem. However, mix temperature appears to be the most likely cause of the observed distress. It is also believed that difficulty in achieving density in SR 1016 is the result of cold mat temperature.

Measures to alleviate the thermal segregation problems include use of material transfer vehicles, insulated trucks, insulated tarps, hopper inserts, and remixing pavers. Finally, when paving in cooler conditions, it becomes more important to maintain the paver hopper full, and to cycle the wings of the hopper so that the colder stones sticking to the wings recycle back into the mix.

1.4 Chapter Summary

Based on the available information, the authors believe the following factors have contributed to the observed scaling of concrete sidewalks:

- There is petrographic evidence that concrete finishing and curing practices were inadequate.
- Concrete had excessive amount of slag cement, and this made it more susceptible to scaling. The slag content should have been kept at 25% of total cementitious materials to mitigate ASR risk but not to increase the scaling risk.
- Concrete had excessive slump, which can lead to excessive bleeding. Imposing an acceptable slump range of 3 to 5 inches would have been more appropriate.
- PennDOT Class A concrete is not an appropriate choice for concrete that is exposed to freezing and thawing, is in continuous contact with moisture, and is exposed to deicing chemical. At a minimum, Class AA should be specified.

Surface segregation and low density were observed on the evaluated asphalt pavements, including on SR 1016. Thermal segregation of the mix is a likely cause of the observed problems. Data such as hauling distance from the plant to the job site, temperature of the mix in the truck at the plant and at the job site, temperature of the mat behind the paver, and information regarding continuity of the paving operation are needed to substantiate this conclusion.

The following PennDOT specification sections have been identified as related to the observed deteriorations. These specification sections will be evaluated in future chapters:

- Publication 408:
  - Section 400: Flexible Pavements; subsections 409, 410, 411, 419, 460
  - Section 501: Reinforced or Plain Cement Concrete Pavements
  - Section 676: Cement Concrete Sidewalks
  - Section 700: Materials: subsections 701-704, 711, 724
  - Section 1001: Cement Concrete Structures
- Bulletin 27: Bituminous Concrete Mixtures, Design Procedures, and Specifications for Special Bituminous Mixtures

Chapter 2. Review of Current PennDOT Specifications and Comparison with National Standards

2.1 Introduction

Chapter 1 identified certain sections of the PennDOT Construction Specifications (Publication 408) that are relevant to the observed deteriorations in District 4. These are:

- Publication 408:
  - Section 400: Flexible Pavements; subsections 410, 413, 419, 460
  - Section 501: Reinforced or Plain Cement Concrete Pavements
  - Section 676: Cement Concrete Sidewalks
  - Section 700: Materials: subsections 701-704, 711, 724
  - Section 1001: Cement Concrete Structures
- Bulletin 27: Bituminous Concrete Mixtures, Design Procedures, and Specifications for Special Bituminous Mixtures

Chapter 2 provides a review of these sections from the current version of PennDOT Publication 408 (Edition 2020, Change 2, effective April 9, 2021), hereafter referred to as "Specifications." The report also provides a comparison with the most recent research and technology development as well as pertinent national specifications and standards to identify any areas where PennDOT specifications may need to be updated. Sections 2.2 and 2.3 are focused on mixture design and construction of concrete sidewalks to ensure adequate performance and durability. Sections 2.4 and 2.5 relate to asphalt mix design and construction to mitigate asphalt pavement distresses.

2.2 Concrete Sidewalks - Literature and Specifications

As stated in Chapter 1, the recently constructed concrete sidewalks on the Wilkes University campus on West South Street and South Franklin Street in the City of Wilkes-Barre, PA have experienced surface scaling (**Figure 1**). Scaling is the deterioration and loss of the top layer (e.g., up to ½ inch deep) of the concrete surface and often occurs as a result of the surface exposure to freezing and thawing in combination with application of deicing salts [15–17]. Scaling may be observed after the first winter of service life. Consequences of surface scaling include changing the appearance and smoothness of the surface, and compromising proper drainage of water, which can lead to ice buildup and an increased risk of slip and fall. In severe cases, the thickness of concrete cover over reinforcing steel is reduced, leading to increased corrosion risk and reduced service life.

Scaling of concrete occurs during freezing and thawing cycles as a result of the expansive forces of freezing pore water near the surface [18]. When water freezes, it expands by approximately 9% [19]. This expansion results in tensile stress buildup inside concrete, and this can lead to cracking. Normally, a well-distributed network of entrained air bubbles that are spaced less than 200 μm from one another is sufficient to mitigate the freeze-thaw stress development and damage within the bulk of concrete [20,21]. However, in horizontal concrete elements, such as sidewalks, pavements and bridge decks, the top surface is often at a higher degree of water saturation due to exposure to rain and snow. Additionally, in cases where the finishing and curing practices have been substandard, the quality of concrete surface is compromised, resulting in a higher water to cementitious materials ratio and porosity, lower air content, and a lower degree of cement hydration at the surface [22]. As such, the tensile stresses caused by freezing of pore water near the surface may exceed the tensile strength of concrete, resulting in surface scaling.

Concrete that is adequately air entrained may still be susceptible to surface scaling when exposed to repeated applications of deicing and anti-acing chemicals (e.g., NaCl, $MgCl_2$, and $CaCl_2$ in solid or brine forms). It has been suggested that in the presence of deicing chemicals, the severity and rate of scaling can be up to 10 times that of the scaling damage caused by freezing and thawing cycles alone [16]. This is especially problematic when deicers are applied within the first few months after construction, when concrete may not have developed adequate microstructure and strength. The following mechanisms have been suggested to explain why deicing chemicals exacerbate surface scaling [15,23]:

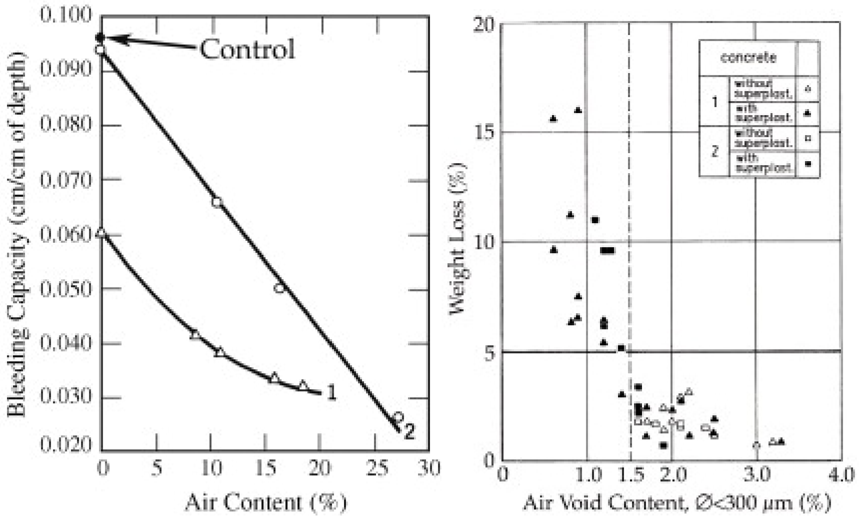
(1) Deicing chemicals cause an increase in the degree of saturation of concrete near the surface, which increases the stress magnitude when the pore water freezes.
(2) The concentration of deicing chemicals varies with the distance from the concrete surface, resulting in development of osmotic stresses.
(3) The salt concentration gradient also results in different freezing temperatures of the pore water and the resulting layer-by-layer freezing of concrete generates stress buildup and cracking near the surface.
(4) Crystallization of deicing salts in the pores upon drying causes tensile stresses and cracking.
(5) The consumption of heat to melt the ice when deicer is applied at the surface causes a rapid drop in the temperature of concrete near the surface and this may lead to damage by rapid freezing of concrete or differential thermal strains.

It has also been reported that chloride-based deicers can react with the calcium hydroxide in concrete, leading to formation of calcium oxychloride, which is expansive and deleterious [24,25].

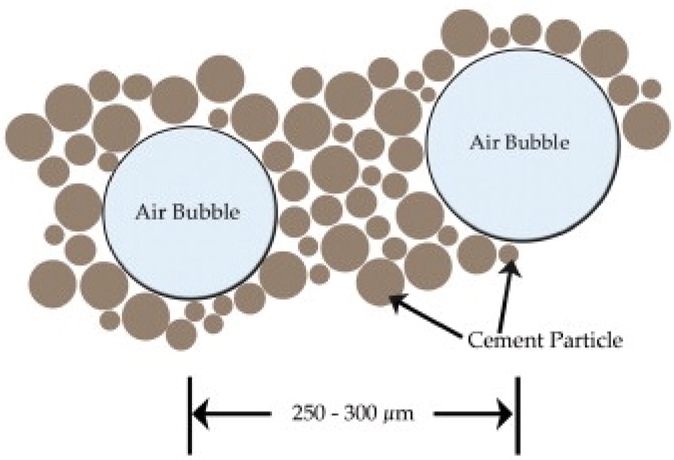
<u>Mitigation of Scaling – Concrete Mix Design Parameters</u>
The scaling risk of concrete sidewalks can be reduced by using good quality, dense concrete that has a sufficiently low w/cm, proper slump, and adequate entrained air, followed by using good practices for construction and curing of concrete and minimizing the use of deicing chemicals to the extent possible [26]. Concrete mixtures with high w/cm have a large volume of free water in capillary pores which are susceptible to freezing. Also, a high w/cm leads to lower strength and higher permeability of concrete which increases its degree of saturation and the penetration depth of deicing salts into the concrete; therefore, increasing the depth of scaling.

Additionally, high w/cm and high slump generally result in more bleeding. Bleeding or bleed water refers to formation of a water layer on the horizontal surface of newly placed concrete. Among concrete ingredients, water has a lower density than aggregates and cement. As a result of gravity, water naturally moves up and accumulates at the horizontal surface of concrete. Generally, the higher the w/cm and slump, the higher the bleeding. Excessive bleeding weakens the concrete surface by increasing the local mortar content and local w/cm and makes the surface prone to cracking and scaling. It can also interfere with setting and hardening of concrete, especially at cooler air temperatures.

Adequate air entrainment of concrete includes achieving a target air content in the range of 4.5% to 7.5% (with a tolerance of ±1.5%), depending on the nominal maximum size of aggregates, and achieving an air void spacing factor of less than 0.008 inch (0.2 mm) [27,28]. While such adequate air entrainment mitigates the hydraulic and osmotic stresses caused by freezing of pore solution [29], it also reduces the risk of damage caused by salt crystallization inside the pores [19]. It has also been reported that using air entraining admixtures can reduce bleeding of concrete by making cement particles buoyant, as illustrated in **Figure 9**.



(a)



(b)

Figure 9. (a) Relationship of air content with bleeding (left) and scaling resistance (right) and (b) schematic diagram of how air bubbles mitigate bleeding (from [22])

<u>Mitigation of Scaling – Construction and Curing Practices</u>

Beyond a proper concrete mix design, proper construction and curing practices are critical to ensure the longevity of concrete sidewalks and their resistance to scaling. Placing exterior concrete in late fall, winter, and early spring is discouraged, as the concrete may be exposed to freezing temperatures shortly after placement and while the concrete is still saturated. For construction of sidewalks, the contractor must check the weather forecast to be prepared for the possibility of wind, rain, snow, freezing, high temperatures, or other adverse conditions. Measures to protect against precipitation, wind, and cold temperatures must be prepared in advance. Concrete must not be placed in freezing temperatures or over frozen subgrade [8]. Concrete should be placed on damp (or moistened) base or subgrade that has been adequately and uniformly compacted. Grades must be established, forms must be secured, any required reinforcement must be in place, and finishing and curing tools must be readily available before commencing the placement of concrete. Concrete must not be placed on vapor barriers.

During placement, concrete must be placed in forms as close to the final location as possible to minimize the need for moving of concrete after placement, which may cause segregation. Gardening rakes must not be used to move concrete [17]. Instead, flat-headed rakes and shovels can be used. Manual screeding or vibratory screeds can be used, but the latter should not be used with concrete that has a slump over 3 inches. Vibratory screeds need to be moved continuously to prevent over-vibrating any sections. Concrete must be consolidated along the formed edges by tamping the concrete with a spade or piece of wood to prevent honeycombing. Bull floating using a magnesium float is recommended after strike-off and before appearance of the bleed water. Bull floating pushes coarse aggregate below the surface and creates a smooth surface.

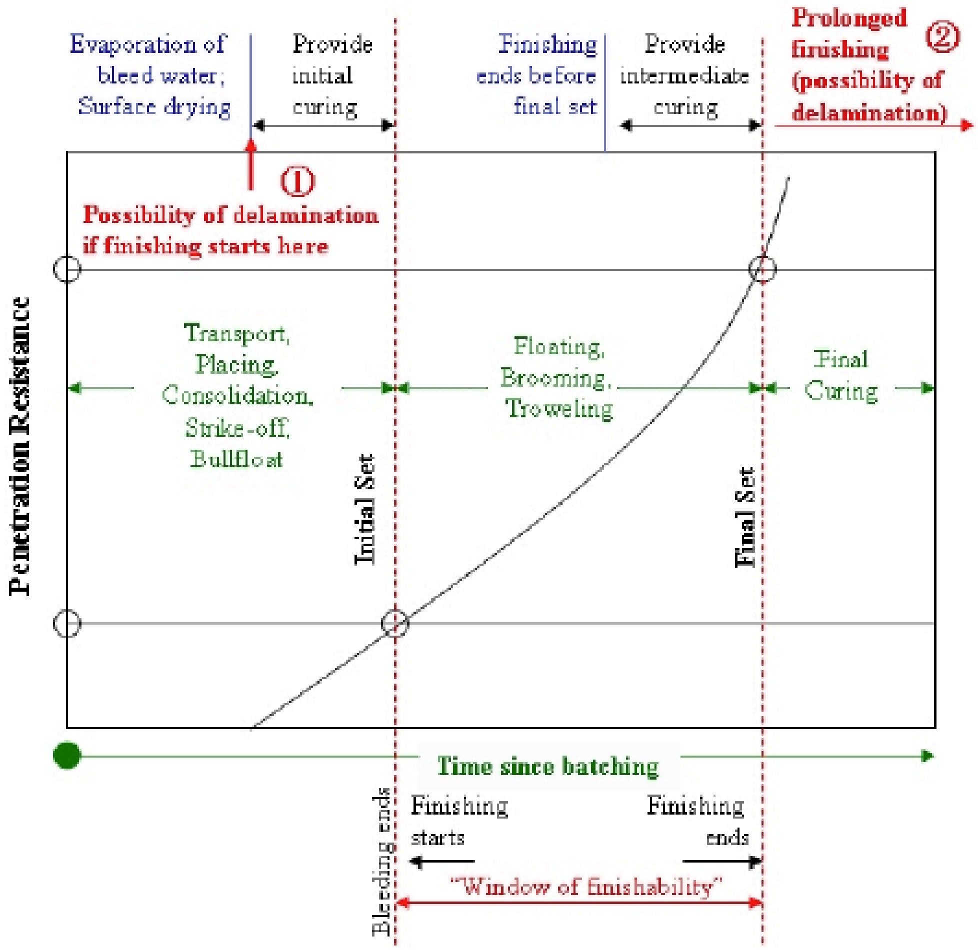


Figure 10. Optimal timing for placement, consolidation, finishing, and curing of concrete (from:[30])

Figure 10 shows optimum timing of various construction operations. After floating, any additional finishing (such as edging, jointing, smoothing, and texturing) must wait until after concrete has passed initial setting, bleeding has completed, and the bleed water has evaporated or been removed using a hose drag. Any finishing operations performed while the concrete is still bleeding will result in later problems, such as dusting, scaling, crazing, delamination, and blisters [17]. To check for setting time, the contractor can use the rudimentary "thumb test" where he/she attempts to press his/her thumb into the concrete surface (see **Figure 11**). If the thumb easily penetrates the surface and wet mortar adheres to the thumb, the concrete has not yet set sufficiently to begin the finishing operations. Alternatively, NRMCA recommends identifying the initial setting time as when a footprint indentation of a person standing on the slab is between 1/8 to ¼ inch (3 to 6 mm).

Figure 11. The "thumb test" to check whether concrete has sufficiently set to begin finishing (from: [8])

Excessive finishing and smoothing of sidewalk surfaces are not needed and increase the scaling risk by increasing the mortar layer near the surface and promoting the loss of air voids. For sidewalks, patios, driveways, and other exterior applications, troweling is not usually required. Air-entrained concrete should not be troweled [17]. In any case, magnesium floats can be used where needed, but steel trowels are discouraged. Use of Fresno and power trowels must be avoided. Intricate finishing operations that require excessive hand-finishing must be avoided if possible.

Reworking of bleed water into the surface or adding water to make finishing easier (a practice known as "blessing" the concrete) result in a weak and high-porosity surface that is prone to scaling and cracking. These practices must be absolutely avoided. According to Mindess et al. [31], "Scaling is most likely to occur on surfaces that have been over-vibrated, troweled too early and too long, subjected to plastic shrinkage, or where excessive bleeding has occurred. Such surfaces tend to have a weak layer of paste or mortar either at the surface or just below and may have microcracks or bleeding channels that can transport surface solutions to lower levels."

Concretes with slow setting, such as those containing supplementary cementitious materials, may bleed slowly and for a long time. On dry and windy days, the bleed water evaporates rapidly, and the surface may dry out before the concrete has begun initial setting and is ready for finishing and curing. This creates a high risk for plastic shrinkage cracking. In such cases, an evaporation retarder must be sprayed over the surface [8,32]. Finishing the concrete before initial setting can trap the residual bleed water near the surface layer, resulting in increased scaling risk [4,32,33].

Appropriate curing is also critical to ensure that concrete achieves its full potential in terms of mechanical and durability performance (e.g., **Figure 12**). Curing refers to actions taken to maintain moisture and heat in newly placed concrete, in order to allow the concrete to develop good quality and strength [32]. When concrete is exposed to evaporation in a plastic state or at early ages, a rapid loss of surface moisture occurs, resulting in stress development and shrinkage cracking [32]. As the water evaporates, cement hydration near the surface ceases, resulting in a higher porosity and a low-strength surface. Similarly, a rapid loss of heat from the surface results in thermal contraction and potential for surface cracking, which itself increases the propensity for future scaling. Therefore, appropriate curing regimes, such as maintaining a wet burlap, protective covers, or proper use of curing compounds, should be employed to prevent rapid moisture loss from concrete. Care should be taken to make sure the surface of newly placed concrete does not dry before conclusion of the required curing period (e.g., 7 days). According to ACI 308R-16, Chapter 4 [32], when the average ambient daily temperature, which is computed as the average of the highest and lowest temperature from midnight to midnight, is above 40 °F (5 °C), the recommended minimum period of maintenance of moisture and temperature for walkways is 7 days for ASTM C150 Type I cement (and 10 days for Type II cement) or the time necessary to attain an in-place strength of at least 70% of the specified 28-day compressive or flexural strength of concrete.

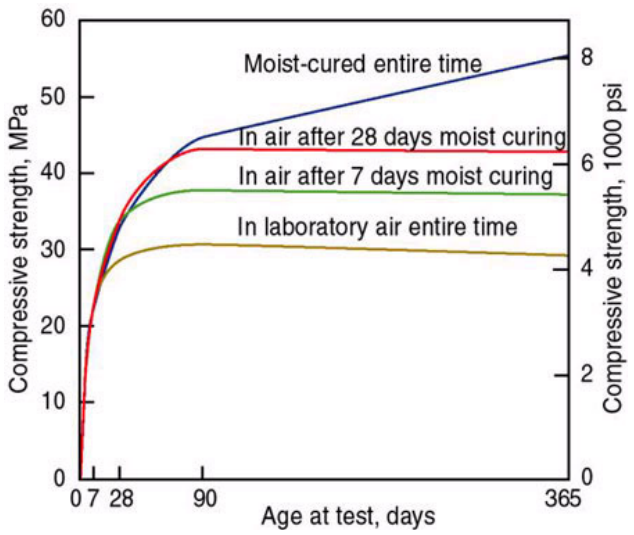


Figure 12. The effect of moist curing on the strength development of concrete (from: [19])

Adequate moist curing should be followed by a period of drying before the surface is exposed to deicing chemicals. After conclusion of curing, application of a breathable sealer (e.g., silane or siloxanes) is encouraged to protect the concrete from deicing salt scaling [8,19]. The sealer creates a protective barrier to minimize penetration of water and deicing chemicals into the concrete. Generally, sealants with solid contents of 25% or higher are recommended.

The Effect of SCMs on Susceptibility to Scaling

SCMs such as coal fly ash and slag cement have been widely used as a partial replacement of portland cement to improve the long-term mechanical properties and durability of concrete. Specifically, SCMs are used to mitigate the alkali silicate reaction (ASR), reduce the risk of thermal cracking, and reduce the permeability and corrosion risk in concrete. The pozzolanic reaction of SCMs consumes the calcium hydroxide in concrete and has been shown to be beneficial for reducing the formation of calcium oxychloride (**Figure 13**) [25,34]. Additionally, the pore refinement due to formation of pozzolanic C-S-H contributes to forming a dense microstructure of concrete, resulting in improved long-term strength and reduction of the ingress of deicing salt solutions. Some SCMs such as calcined clay and slag may also reduce the bleeding of high w/cm concrete [35].

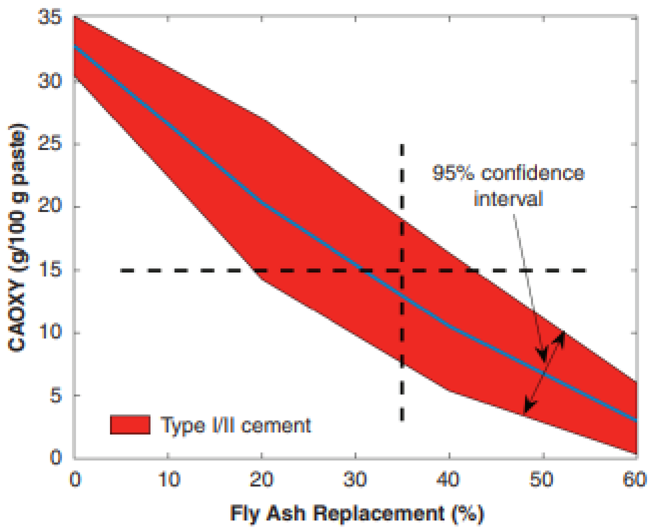


Figure 13. Higher replacement of portland cement with fly ash reduces the mass of calcium oxychloride that forms in exposure with deicing salts [34]

At the same time, concretes with a high SCM dosage, especially those containing slag, have been reported to be prone to scaling damage. A significant reduction in the scaling resistance has been observed when slag content was higher than 30% [36]. This is more related to how SCMs impact the fresh properties and setting of concrete and highlights the significance of proper finishing and curing practices to make sure such concretes achieve their full potential and durability. A large SCM dosage can considerably delay the time of setting and slow down the early-age strength development in concrete [37]. This is especially problematic during cool and cold season construction. Contractors may be tempted to finish the workday before concrete is past initial setting, and to do so, they may finish the concrete surface before bleeding has concluded and the bleed water has evaporated. Finishing and curing practices may also happen in a hurry when they are performed late in the day. As such, contractors must have a plan in place to make sure that proper finishing and curing of concrete are not compromised when concrete contains SCMs. For example, excessive SCM dosages beyond those needed for ASR mitigation should be avoided. Type III portland cement or accelerating admixtures can be used to shorten the setting time. In concretes with frequent exposure to water and exposure to deicing chemicals, the maximum dosage of fly ash should not exceed 25% and the maximum dosage of slag should not exceed 50% [27].

ASTM C672, Standard Test Method for Scaling Resistance of Concrete Surfaces Exposed to Deicing Chemicals, can be used to evaluate the susceptibility of a concrete mixture to surface scaling [38–40]. In this specification, the surface area and depth of specimens should be higher than 0.045 m^2 and 75 mm, respectively. At least two duplicate samples should be made and tested. The samples should be cured in a moist room as specified in ASTM C511 [41] for 14 days and stored in air for another 14 days at 23±2 °C temperature and 45–55% relative humidity conditions. For testing, the top surface of a moist cured slab sample is ponded with a salt solution made of 4 g $CaCl_2$ per 100 ml of water. The sample is then placed in a freezer at -18±3 °C for 16 to 18 hours, followed by drying in laboratory air at relative humidity of 50±5% and temperature of 23±2 °C for 6 to 8 hours. This cycle is repeated every day. Water is added between freezing and thawing cycles to maintain the depth of solution on the top surface of the concrete samples. The visual rating of severity of concrete surface scaling is recorded in accordance with **Table 2** after 5, 10, 15, 25, and 50 cycles.

Table 2. Determination of severity of concrete surface scaling

Rating	Condition of surface
0	No scaling
1	Very slight scaling (3 mm depth, max, no coarse aggregate visible)
2	Slight to moderate scaling
3	Moderate scaling (some coarse aggregate visible)
4	Moderate to severe scaling
5	Severe scaling (coarse aggregate visible over entire surface)

In the following, a review of pertinent sections of PennDOT Publication 408/2020-2 is provided and a comparison is made with national standards. Specifically, areas where the two disagree are emphasized. Suggestions for improving the PennDOT specifications are presented with *italic font*.

2.3 Scaling of Concrete Sidewalks - Relevant PennDOT Specifications in Comparison with National Standards

Concrete Mix Design

According to PennDOT Publication 408, Section 676, "Cement Concrete Sidewalks," Class A cement concrete with the following characteristics (**Table 3**) must be used for construction of sidewalks. According to Specification's Section 704, "Cement Concrete," concrete mix design must be performed according to ACI 211. The concrete must have a plastic state air content of 6.0±1.5%. The maximum slump must be 5 inches when water reducing-admixtures (WRA or plasticizer) are not used, 6.5 inches when WRA is used, and 8 inches when high range WRA (superplasticizer) is used. A tolerance of ±1.5 inches from target slump value is allowed as long as the aforementioned maximum slump values are not exceeded. Concrete temperature at the time of placement must be maintained between 50 °F and 90 °F.

Table 3. Criteria for Class A cement concrete (Source: Publication 408/2020-2, Section 704)

Class of Concrete	Use	Cement Factor (lb/yd^3)	Max. w/cm	Min. Mix Design Compressive Strength (psi)	28-day Structural Design Compressive Strength (psi)
Class A	Structures and Misc.	564 – 752	0.50	2,750 at 7 days 3,300 at 28 days	3,000

According to Specification's Section 704, supplementary cementitious materials may be used as a partial replacement of portland cement. The use of SCMs or lithium nitrate admixtures is mandatory when concrete contains ASR-susceptible aggregates, such as those exhibiting expansion greater than 0.04% in ASTM C1293 test [42]. The required quantity of SCM to mitigate ASR is determined using the protocol in section 704.1(g) of Specification. The protocol takes into account the ASR reactivity level of the aggregates and classification (e.g., design service life) of the structure. For sidewalks constructed using moderately reactive (Class R1) aggregates, such as those used in the Wilkes University project, a minimum of 15% to 20%

fly ash (depending on the fly ash alkali content) and a minimum of 25% slag cement by mass of total cementitious materials is required to mitigate ASR. The maximum allowable SCM content is 35% to 40% for fly ash and 65% for slag cement. Table G of Section 704.1(g) of Specifications notes that "The use of high levels of SCMs in concrete may increase the risk of problems due to deicer salt scaling if the concrete is not properly proportioned, finished, and cured."

As discussed earlier, concrete with high w/cm is prone to surface scaling and inadequate freeze-thaw durability. According to ACI 318-19 code [27], Chapter 19, concrete exposed to freezing and thawing cycles with frequent exposure to water and exposure to deicing chemicals is classified as having "Very severe – Class F3" exposure with respect to freezing and thawing. According to this code, to ensure freeze-thaw durability in such an environment, non-reinforced concrete must have a minimum 28-day compressive strength of 4,500 psi and a maximum w/cm of 0.45. NRMCA CIP-2 and ACI 332 "Code for Residential Concrete" recommends concrete with a minimum 28-day compressive strength of 4,000 psi [26,43]. *PennDOT Class A concrete does not meet these requirements, as it has a minimum 28-day compressive strength of 3,300 psi and a maximum w/cm of 0.50. As such, it is recommended to specify building sidewalks using a higher class of concrete, such as Class AA at a minimum.*

Additionally, concretes containing large SCM dosages may be prone to surface scaling, as these concretes often exhibit considerable delays in the time of setting as well as slow strength development at early ages [37]. In such circumstances, there is an elevated risk that finishing and curing practices may be performed inadequately and in a hurry. This can compromise the quality of concrete containing SCMs specifically as it relates to surface scaling and cracking. For these reasons, the Slag Cement Association recommends using concrete mixtures incorporating slag to have w/cm below 0.45 [44]. Similarly, the National Concrete Pavement Technology Center reported that slag content less than 35% exhibited sufficient scaling resistance at low w/cm in the range of 0.38–0.42 [45]. Tavasoli et al. [36] reported that concrete mixtures incorporating up to 30% slag cement showed adequate compressive strength and freeze-thaw resistance, but mixtures with slag content in the range of 50% to 80% showed poor strength and freeze-thaw resistance. For the Wilkes University project, 25% slag cement was sufficient to mitigate ASR (according to Publication 408, Section 704.1(g)), but the concrete contained 40% slag. *Overall, it is advisable to avoid using excessive SCM dosages beyond those needed for ASR mitigation. Also, for construction with concrete containing SCM, contractors must develop a plan to be approved by PennDOT to make sure that proper finishing and curing of concrete is not compromised.*

High-slump concrete is prone to excessive bleeding and elevated scaling risk. ACI document 211.1 recommends slump for pavements and slabs in the range of 1 to 3 inches [7]. PennDOT specifications allow for slump to be up to 8 inches, while the Wilkes University project had slump in the range of 3.75–6 inches. *Lowering the maximum slump to 5 inches is advisable for sidewalks*. This is in line with [8,26].

<u>Construction and Curing</u>

Section 676 of Specification states "[Construct concrete sidewalks] as specified in Section 1001.3. Place concrete 4 inches deep. Strike off, finish, and test, as specified in Sections 501.3(k) and (p), except the contractor may use manual placement operations and apply a light broom finish to the cement concrete surface." Section 1001.3 does not allow adding water to concrete in the field, unless authorized in writing by the District Executive. In that case, a maximum of 1 gallon per cubic yard of concrete may be allowed as long as the maximum permitted w/cm is not exceeded.

Construction and finishing of sidewalks must be performed according to Section 501.3(k), which allows for machine or manual strike-off and consolidation. Subsequently, concrete must be floated, subjected to straightedge testing and surface correction, and then a final broom finish is performed.

Adding water or monomolecular film to the concrete surface to assist in finishing is prohibited. Sidewalks must not be over-finished. Section 1001.3(k)1 specifies "Finish exposed concrete surfaces accurately and evenly, free from open and rough areas, and free from depressions and projections. Strike off with a straightedge and float to the correct elevation. Do not add water or curing agent to the concrete surface to assist in finishing."

Curing is specified in Section 1001.3(p), which requires curing to begin as soon as the concrete has been placed and is sufficiently hardened. Curing can be via liquid membrane-forming curing compounds (CC) that must be applied according to the manufacturer's recommendation. CC must be applied to unformed surfaces after the final finish and after the surface film of bleed water has disappeared. Formed surfaces must be sprayed by CC immediately after stripping the forms. Formed surfaces must be wetted and the CC is applied as the surface film of water disappears. For all surfaces, CC must be applied in two coats, by spraying, to provide a continuous, uniform membrane. For each coat, at least 1 gallon CC per 300 ft^2 of concrete must be applied. After the first application has set, the second coat must be applied at a direction perpendicular to the first application. CC must be protected from damage (e.g., by foot traffic) for a minimum of 7 days.

Alternatively, water curing may be employed via a double thickness of burlap, white polyethylene sheeting placed on top of a single layer of burlap, or burlap-backed white polyethylene sheeting. Curing covers must be saturated before use and kept in a saturated condition for the duration of curing. Curing covers must be placed on unformed surfaces as soon as concrete can support them without producing marring of the finished surface. Formed surfaces must be covered with pre-saturated curing covers as soon as forms or sections of forms are loosened or removed. Water curing must continue for a minimum of 7 days and until the 7-day QC compressive strength of concrete exceeds the minimum mix design compressive strength from **Table 3**. Otherwise, water curing must continue until the specified 28-day minimum mix design compressive strength is obtained. Concrete temperature must be maintained above 50 °F during the 7-day curing period.

According to Section 676.3(f), side forms can be removed after 12 hours from placement of concrete. Minor honeycombed areas should be filled with mortar while major honeycombed areas must be removed and replaced. Boiled linseed oil must be applied to the entire surface of the concrete as specified in Section 1019.3(a). If curing was performed with a membrane-forming curing compound, the curing compound must be removed before placing the boiled linseed oil. It is unclear, although likely intended, that this action should be performed after 7 days of curing using CC.

The above PennDOT specifications for construction and curing of concrete sidewalks are in line with national specifications and the latest research recommendations. The required application of boiled linseed oil to serve as a surface sealant is a good practice to further reduce the risk of deicing salt scaling. Construction inspectors must make sure that these specifications are followed carefully to ensure that the quality and performance of sidewalks are not compromised. For example, sometimes curing compounds are applied incorrectly or insufficiently, and this must be prevented (**Figure 14**).

Figure 14. Insufficient application of curing compound results in insufficient curing and ultimately scaling of concrete surfaces (from: [8])

Adding the following statements to Section 676.3(d) is recommended to further reinforce the Specification's requirements for quality construction and curing practices for concrete sidewalks. "*After floating and straightedge testing, any additional finishing of concrete surface must wait until after the bleeding has completed and the bleed water has evaporated or has been removed, and after the initial setting of concrete. Adding water to make finishing easier or reworking of bleed water into fresh concrete surface are prohibited. Excessive finishing or troweling of the concrete surface using Fresno and power trowel are not permitted. Curing must be commenced immediately after finishing. Care must be taken to make sure the exposed concrete surfaces never dry out. If curing is delayed for any reason, an intermediate monomolecular film curing agent must be applied to protect the surface.*"

It is also advisable to require that concrete finishers are certified according to ACI Flat Work Finisher Certification [46] *or NRMCA Exterior Concrete Finisher Certification* [47]. *The statement regarding application of boiled linseed oil needs to be clarified to indicate that linseed oil must be applied after the required 7-day curing.*

Winter Maintenance

NRMCA recommends avoiding the use of deicing chemicals on newly placed concrete and to instead use clean sand for traction [26,48]. Deicing chemicals composed of calcium chloride and sodium chloride (rock salt) are acceptable for concrete but ammonium sulfate, ammonium nitrate, or magnesium-based salts must be avoided as they are chemically aggressive and harmful to concrete surfaces. *Use of magnesium- and ammonium-based deicers and anti-icers should not be permitted within PennDOT specifications for deicing of concrete pavements, bridge decks, sidewalks, and other horizontal surfaces.*

2.4 Asphalt Pavements - Literature and Specifications

The progressive evolution in asphalt mix design and construction is the result of collective efforts from many agencies and organizations. Advanced research in universities and research institutes continues to be among the major contributors to the changes that occur in asphalt mix design specifications. The Federal Highway Administration (FHWA) has established various expert task groups (ETG), such as the asphalt mix design ETG and asphalt binder ETG, to discuss the needed research and bring the latest technologies to the design and construction of asphalt pavements. The National Cooperative Highway Research Program (NCHRP), a research arm of the National Academy of Sciences, spends a substantial budget annually to research the pressing matters in the area of asphalt materials and construction. The results of research efforts on materials and pavements finally are brought into implementation through efforts of the Committees on Materials and Pavements of the American Association of State Highway Transportation Officials (AASHTO) and American Society of Testing and Materials (ASTM). Since AASHTO is the association representing all 50 states, all state highway agencies develop their specifications based on AASHTO recommendations. To add to the list, the National Asphalt Pavement Association (NAPA) has valuable publications that have been generated by experts in the field. These publications certainly complement all other relevant documents published by FHWA, AASHTO, ASTM, NCHRP, Transportation Research Board (TRB) of the National Academy of Sciences, research institutes, and asphalt pavement associations of various states. Collectively, these documents provide the base for specifications developed by state highway agencies.

In this section, the findings from some of the preceding documents are discussed in the light of the most recent PennDOT specifications, and recommendations are provided on the items to be considered in providing the revisions to future PennDOT asphalt-related specifications. It should be mentioned that PennDOT has been among the states in the forefront of implementing many recent findings in the area of asphalt mix design and asphalt pavement construction, and PennDOT representatives are heavily involved with various asphalt-related expert task groups and committees.

<u>The Superpave Mix Design System</u>

The Superpave mix design system was developed by the Strategic Highway Research Program (SHRP) under collaborative effort with FHWA, AASHTO, and TRB. Superpave stands for Superior Performing Asphalt Pavements and was developed to replace the conventional Marshall and Hveem methods of asphalt mix design. In the Superpave design, asphalt binders and aggregates are selected considering traffic and climate conditions. Superpave mixture design requires the selection of suitable materials, volumetric parameters criteria, and application of gyratory compaction using a laboratory compaction method. Quality criteria for the materials and the laboratory compaction levels are associated with the traffic classification. Compaction levels, in terms of the number of gyrations, have been modified by some states to more closely match field compaction efforts.

<u>Asphalt Binder Requirements in the Superpave System</u>

Superpave asphalt binder performance grade (PG binders) designations are connected to design values selected for the average seven-day maximum pavement temperature and minimum pavement temperature. The pavement temperature design values are selected at a specified level of reliability, most often 98%. For example, PG 64-22 binder, which was used for asphalt pavements at SR1016 and SR2020, is for use at a project site where the average 7-day maximum pavement temperature does not exceed 64 °C and the expected minimum pavement temperature is not lower than -22 °C. According to Bulletin 25 [49], PG binder supplier requirements, the delivery and placement temperatures for PG 64-22 should be in a range of 265–320 °F (130–160 °C). The specifications and requirements of PG binders are listed in AASHTO M 320 [50]. These requirements cover flash point temperature (AASHTO T 48 [51]), viscosity (AASHTO T 316 [52]), dynamic shear (AASHTO T 315 [53]), creep stiffness (AASHTO T 313 [54]), and direct tension (AASHTO T 314 [55]). The procedures for binder conditioning before testing and characterization are through either short-term aging with the rolling thin-film oven (AASHTO T 240 [56]) or long-term aging with the pressurized aging vessel (AASHTO R 28 [57]).

Within the last few years, there have been significant changes in asphalt binder specifications, with the latest changes reflected in AASHTO Specification M 332 [58]. These revisions were mainly developed for better characterization of polymer-modified binders and bringing the traffic level into designation of the asphalt binder. The traffic designations are standard (S), heavy (H), very heavy (V), and extreme (E). While many states continue to use AASHTO M 320 [50], PennDOT has already adopted these revised binder specifications, as reflected in the initial edition of Publication 408. In this revised specification, PG 64-22 has been replaced by PG 64S-22, and PG 76-22 by PG 64E-22. The standard test behind AASHTO M 332 specification [58] is AASHTO T 350 (Test for Multiple Stress Creep Recovery) [59]. The main engineering parameters measured in AASHTO T 350 are the binder creep compliance and the ability of the binder to recovery of deformation under unloading.

Asphalt Mixture Requirements in the Superpave System

PennDOT Bulletin 27, Chapter 2A [60], is the governing document for PennDOT Superpave mix design, and is heavily related to AASHTO test protocols and standards, specifically AASHTO M 323 [61]. Asphalt mixtures need to meet the requirements of volumetric properties of Superpave volumetric criteria with respect to air voids (V_a) at different numbers of gyrations ($N_{initial}$, N_{design} and N_{max}), voids in mineral aggregates (VMA), voids filled with asphalt (VFA), and the ratio of percent of material passing the #200 sieve over the effective asphalt content. The standard test followed by PennDOT to determine the density of asphalt mixture using Superpave gyratory compactor is AASHTO T 312 [62].

Warm Mix Technology

For the construction of asphalt pavement at SR 1016 and SR 2020 in District 4, warm-mix asphalt (WMA) was adopted. In general, mixtures using WMA technology are mixes that can be manufactured and placed at significantly lower temperatures than hot-mix asphalt (HMA), sometimes 60–70 °C lower. **Figure 15** is a useful reference indicating the terminology associated with temperature of asphalt mixtures. The classification as provided in **Figure 15** is HMA (150–190 °C), WMA (100–140 °C), half-warm mix asphalt (60–100 °C), and cold mixes (0–40 °C) [63]. The low-temperature mixing and placing technology of WMA is beneficial for reducing the use of fossil fuels as well as emission of carbon dioxides due to low mixing and compaction temperatures [64]. Furthermore, construction benefits include extension of the paving season (cooler months), ability to haul material longer distances, improvement of compaction at lower temperatures, and use of higher amounts of RAP. WMA has been applied in many types of asphalt concrete, such as dense-graded, and stone matrix porous asphalt [65].

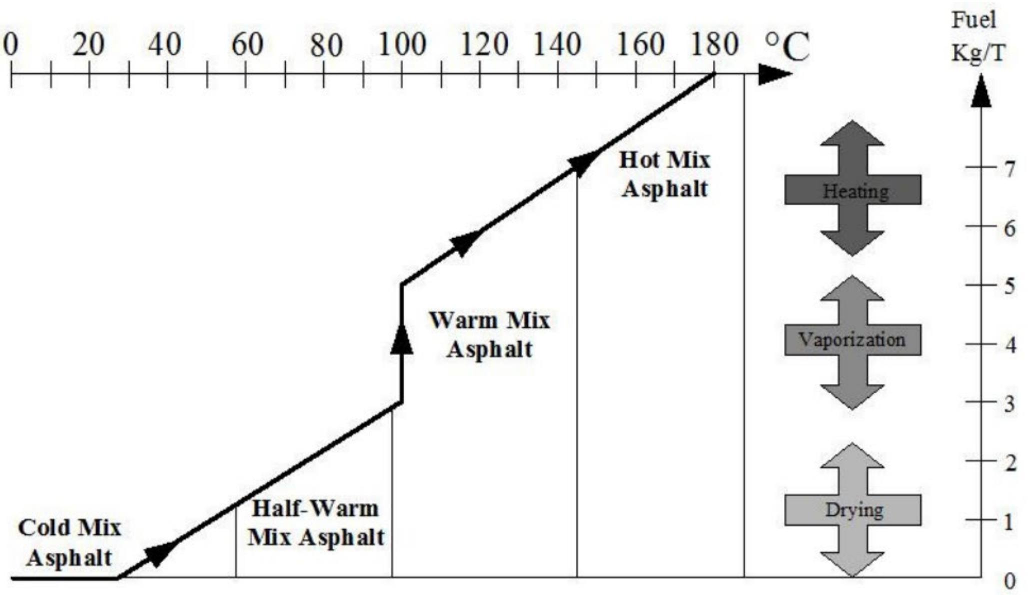


Figure 15. The classification of asphalt mixes in accordance with production temperature and fuel consumption (from [66])

2.5 Segregation of Asphalt Pavements - Relevant PennDOT Specifications in Comparison with National Standards and Latest Research

The asphalt surface segregation and low-density issues at SR 1016 and SR 2020, as specified in Chapter 1, might be attributed to the cold weather paving (Exhibit K late season paving request until Nov. 22nd, 2019) as well as limitations in compaction (Exhibits H, I and J). Under Task 2, the research team was charged to review current PennDOT specifications as well as national standards and specifications in the light of findings related to distresses observed on SR 1016 and SR 2020. To this effect, current PennDOT specifications and various pertinent documents were reviewed. The reviewed documents were related to mix design, RAP content, tack coat application, antistripping agents, and cold weather paving.

<u>Mix Design Information for SR1016 and SR2020</u>
The information on bituminous concrete mix design used for SR1016 and SR2020 is provided in **Tables 4–8** (Exhibit G of received documents).

Table 4. Bituminous concrete mix design used for SR1016 and SR2020 (Exhibit G)

Bituminous supply code	JMF number and year	State route	Material	Asphalt	Design ESALs	Skid resistance level
STA57C41	W95221E1 2019	SR1016, SR2020	9.5 mm	PG 64-22	0.3–3	E
STA57C41	W19121E1 2019	SR1016, SR2020	19 mm	PG 64-22	< 3	E
STA57C41	W25121E1 2019	SR1016, SR2020	25 mm	PG 64-22	< 3	E
VAS40A4A	W25122E1 2019	SR1016, SR2020	25 mm	PG 64-22	< 3	E
VAS40A41	W19122E1 2019	SR1016, SR2020	19 mm	PG 64-22	< 3	E

Table 5. Warm mix asphalt concrete mixture design

		Supplier	Characteristics (SR1016 & SR2020)
Warm mix asphalt concrete (2019, JMF W95222E2)	**Fine aggregate**	Supplier code: VSQ40A14 New Enterprise Stone & Lime Co., Inc., 215 E Saylor Ave. Laflin, PA 18702	Type B, #3 Specific gravity: 2.669 %Material: 39.5% Absorption: 1.12%
	Coarse aggregate	Supplier code: WHR40A14, White Haven Red Rock, Sales, PA	Type A, #8 Specific gravity: 2.706 %Material: 36.0% Absorption: 0.79% Skid resistance level: E
	Warm mix asphalt	Supplier code: SUIT3 15 Suit-Kote Corporation, 1911 Lorings Crossing Road, Cortland, NY 13045-5160	EVO-M1 (Evotherm M1) Antistripping additive and warm mix additive.
	Hot RAP design (reclaimed asphalt pavement, RAP)	Supplier code: VAS40A41 New Enterprise Stone & Lime Co 202 Main Street Laflin, PA 18702	Specific gravity: 2.725 %Material: 20.0%
	Asphalt binder	Supplier code: SUIT3 15 Suit-Kote Corporation, 1911 Lorings Crossing Road, Cortland, NY 13045-5160	PG 64-22 Specific gravity: 1.030 %Material: 4.5%

Table 6. Job mix formula and design

Design asphalt binder content %	% virgin asphalt concrete	Virgin asphalt concrete PG binder grade	% reclaimed asphalt concrete from RAP	Total reclaimed binder ratio
5.8%	4.5%	PG 64-22	1.3%	0.22
Total % asphalt binder content (Pb)	**% effective asphalt binder (Pbe)**	**Fines / asphalt ratio**	**Calculation of asphalt film thickness**	
5.8%	5.6%	0.8	9.50	

Table 7. Mix characteristics (gyratory)

Design equivalent single axle loads (ESALs)	Gyrations (air voids)			Voids in mineral aggregate (VMA)	Voids filled with asphalt (VFA)	Bulk specific gravity of combined aggregate
	$N_{initial}$	N_{design}	N_{max}			
0.3–3 million	7 (11.9%)	75 (4.0%)	115 (3.0%)	16.8%	76.0%	2.695
Theoretical max specific gravity	**Bulk specific gravity of mixture**	**Theoretical max density**	**Bulk density of mixture**	**Asphalt calibration factor for asphalt content (PTM No. 757)**	**Asphalt calibration factor for #200 sieve (PTM No. 757)**	**Tensile strength ratio (TSR)**
2.480	2.380	154.4 lb/ft^3	148.1 lb/ft^3	0.84	0	0.98

*Sample size: 150 mm in diameter

Table 8. Combined aggregate properties

AASHTO T 176 Sand equivalency (%)	AASHTO T 304 fine aggregate angularity uncompacted voids (%)	ASTM D5821 – Coarse aggregate angularity		ASTM D4791 Flat/elongated particles		Total %reclaimed aggregate from reclaimed asphalt pavement (RAP)
		%1 Face crush	%2 Face crush	5:1	3:1 SMA only	
64.0%	49.0%	100%	100%	2.5	-	18.7%

Mix Design Requirements

The asphalt mixture design requirements are provided in AASHTO M 323 [61] and Bulletin 27, Chapter 2A (see **Table 9**) [60]. The asphalt mixture compacted in accordance with AASHTO T 312 [62] should meet the relative density, VMA, VFA, and dust-to-binder ratio requirements specified in **Table 9**, with the revisions specified in Bulletin 27, Chapter 2A [60]. In a comparison to the design requirements, the job mix formula for the projects on SR1016 and SR2020 satisfies all the design requirements, and that is expected as it is an approved mix design.

Table 9. Revised Superpave asphalt mixture design requirements in accordance with Bulletin 27 2A [60] (original: AASHTO M 323 [61])

Design ESALs (million)	**Required relative density, % max.**			**Voids in the mineral aggregate (VMA), % min.**						**Voids filled with asphalt (VFA)**	**Dust to binder ratio**
				Nominal maximum agg. size, mm							
	$N_{initial}$	**N_{design}**	**N_{max}**	**37.5**	**25.0**	**19.0**	**12.5**	**9.5**	**4.75**		
< 0.3	91.5%	96.0%	98.0%	11.0 - > 11.5	12.0 - > 12.5	13.0 - > 13.5	14.0 - > 14.5	15.0 - > 15.5	16.0	70-80	0.6-1.2
0.3–3	90.5%	96.0%	98.0%	11.0 - > 11.5	12.0 - > 12.5	13.0 - > 13.5	14.0 - > 14.5	15.0 - > 15.5	16.0	65-78	0.6-1.2
3–10	89.0%	96.0%	98.0%	11.0 - > 11.5	12.0 - > 12.5	13.0 - > 13.5	14.0 - > 14.5	15.0 - > 15.5	16.0	65-75	0.6-1.2
10–30	89.0%	96.0%	98.0%	11.0 - > 11.5	12. 0- > 12.5	13.0 - > 13.5	14.0 - > 14.5	15.0 - > 15.5	16.0	65-75	0.6-1.2
> 30	89.0%	96.0%	98.0%	11.0 - > 11.5	12.0 - > 12.5	13.0 - > 13.5	14.0 - > 14.5	15.0 - > 15.5	16.0	65-75	0.6-1.2

RAP in the Asphalt Mix

The asphalt mixtures used for the construction at SR 1016 and SR 2020 contained 20% reclaimed asphalt pavement (RAP). According to Bulletin 27 Appendix H (Superpave Design Guidelines for Using Hot-Mix Recycled Asphalt Pavement and Recycled Asphalt Shingles) [60], when an asphalt mixture contains greater than 15% RAP (Tier 2), RAP gradation and asphalt content must be determined, and an evaluation must be conducted to determine the performance grade of the RAP binder, with the goal of using a blending chart to determine the target performance grade. For the mixes placed on SR 1016 and SR 2020, it is not clear from the reviewed documents what performance grade was found for the RAP binder and what was the grade of the final blend of the virgin binder and RAP binder. However, the RAP content used in the mix is allowed by PennDOT specifications.

Faheem et al. [67] reported that WMA mixes with 15% RAP can meet volumetric limits at the warm production temperature levels. It has been reported that WMA mixtures with 0% and 25% RAP showed high rutting resistance under a 30-million ESAL traffic level. WMA with 25% RAP required a slightly higher asphalt content (4.1–5.1% vs. 4.9–5.5%, for nominal max. aggregate size of 12.5 mm) at 4% air voids [68]. Hill [69] reported that the performance of asphalt mixtures (PG 64-22) containing virgin and 45% RAP and WMA additives (3% Sasobit, 0.5% Evotherm) showed sufficient rutting resistance and moisture and fracture resistance. The maximum RAP content can also be estimated as specified in AASHTO R 35 Appendix X2 [70]. A range of RAP content in WMA mixtures is similar to that in HMA. For HMA, it has been reported that the appropriate RAP content is in a range of 14–36%, which satisfies the requirement of a blended PG 64-22/Rap binder as provided in NCHRP Report 452 [71]. Similarly, the HMA pavements containing up to 30% RAP showed similar performance to that of pavements using virgin materials with no RAP [72].

Table 10. Combined aggregate gradation specified in Bulletin 27 2A [60]
(original: AASHTO M 323 Section 6 [61])

Sieve size	Cumulative percentage	
	JMF W95222E2	Requirements (Nominal maximum agg. size: 9.5 mm)
1/2” (12.7 mm)	100%	100%
3/8” (9.51 mm)	95%	90–100%
#4 (4.76 mm)	66%	up to 89%
#8 (2.38 mm)	47%	32–67%
#16 (1.19 mm)	35%	-
#30 (0.595 mm)	26%	-
#50 (0.297 mm)	17%	-
#100 (0.149 mm)	9%	-
#200 (0.074 mm)	4.5%	2–10%

It should be noted that during production the aggregates gradation, asphalt content, and temperature of mixture should conform to the composition tolerance requirements as specified in Section 413.2(e) as summarized in **Table 11**. During construction, the volumetric properties of mixtures should conform to the tolerance of air voids and VMA as shown in **Table 12**.

Table 11. Composition tolerance requirements
(Pub 408/2020-2, Section 413.2 Table A)

			Single sample (n = 1)	Multiple samples (n ≥ 3)
Gradation				
Passing 12.5 mm and larger sieves			± 8%	± 6%
Passing 9.5 mm to 150 µm sieve			± 6%	± 4%
Passing 75 µm sieve			± 3.0%	± 2.0%
Asphalt content				
19.0 mm asphalt mixtures and smaller			± 0.7%	± 0.4%
25.0 mm asphalt mixtures and larger			± 0.8%	± 0.5%
Temperature of mixture (°F)				
Class of material	**Type of material**	**Chemical, organic, foaming additives minimum**	**Mechanical foaming equipment/process minimum**	**Maximum**
PG 58S-28	Asphalt binder	215 °F	230 °F	310 °F
PG 64S-22	Asphalt binder	220 °F	240 °F	320 °F
PG 64E-22	Asphalt binder	240 °F	260 °F	330 °F
All other binders	Asphalt binder	The higher of 215 °F or the minimum temp. specified in Bulletin 25 minus 45 °F	The higher of 230 °F or the minimum temp. specified in Bulletin 25 minus 30 °F	As specified in Bulletin 25

Table 12. Volumetric tolerance requirements of the laboratory compacted mix (Pub 408/2020-2, Section 413.2 Table B)

Property	Each specimen	Multiple specimens
Air voids at N_{design} (Va)	± 2%	± 1.5%
Minimum VMA % for 4.75 mm	16.0	-
Minimum VMA % for 9.5 mm	15.0	-
Minimum VMA % for 12.5 mm	14.0	-
Minimum VMA % for 19.0 mm	13.0	-
Minimum VMA % for 25.0 mm	12.0	-
Minimum VMA % for 37.5 mm	11.0	-

Tack Coat

Most pavements are usually made up of multiple layers, thus it is critical that the layers be properly bonded together to prevent premature failure, such as slippage, delamination, and cracking [73]. A tack coat of asphalt (usually emulsified asphalt) is applied to ensure bond between the existing surface and the asphalt overlay. Tack coat is sprayed on an asphalt binder upon an existing asphalt or portland cement concrete pavement. Tack coats should be applied sufficiently, as determined based on residual asphalt content, and uniformly to improve bonding [74]. A good tack coat application will assist compaction and provide an improved bond, resulting in better long-term performance. It should be noted that the main factors affecting the emulsion break and set times are highly related to application rate, surface temperature, and climate conditions.

All contracts with Superpave material should specify either an asphalt tack coat conforming to Pub 408 Section 460 or asphalt prime coat conforming to Pub 408 Section 461. Application rates are specified in each section. However, the Project Engineer must select an appropriate application rate within the specifications based on the porosity of the existing surface being overlaid as provided in PennDOT Pub 242. A lower application rate is intended for very smooth nonporous surfaces. A higher application rate is desirable for more porous surfaces. The most common tack coat materials are asphalt emulsions with slow setting (e.g., SS-1, SS-1h, CSS-1, and CSS-1h) and rapid setting (e.g., RS-1, RS-2, CRS-1, and CRS-2). Information on applicable tack coat and prime coat is provided in Sections 460 and 461. The class and application temperature of emulsified asphalt materials are provided in **Table 13**. Details on tack coat (Tack and NTT/CNTT) and prime coat (AE-P and E-1 Prime) are provided in Bulletin 25 [49]. According to Section 460, the tack coat can be applied when the air temperature is 40 °F or higher and the existing surface is dry. The tack coat should be applied at an application rate to be within ranges of the uniform asphalt residual rate, which can vary depending on the surface type as listed in **Table 14**. The residual rates specified with PennDOT are comparable with those reported in the FHWA Tech Brief report (**Table 14**) [75].

Table 13. Emulsified asphalt materials (Pub 408/2020-2, Section 460, Table A)

Class of material		**Type of material**	**Application temperature**	
			Minimum	**Maximum**
Tack coat (Pub 408, Section 460)	Tack	Anionic or cationic emulsified asphalt	90 °F	150 °F
	Non-tracking tack coats (NTT/CNTT)	Anionic or cationic emulsified asphalt	140 °F	180 °F
Prime coat (Pub 408, Section 461)	AE-P	Emulsified asphalt	90 °F	150 °F
	E-1 Prime	Emulsified asphalt	100 °F	170 °F

Table 14. Recommended tack coat application rate (Pub 408/2020-2, Section 460, Table B)

Surface type	**Residual rate (gal/yd^2)**	
	Pub 408/2020-2, Section 460	**FHWA Tech Brief Tack Coat Best Practices 2016**
New asphalt	0.03–0.05	0.02–0.05
Existing asphalt	0.04–0.07	0.04–0.07
Milled surface	0.04–0.08	0.04–0.08
Portland cement concrete	0.04–0.07	0.03–0.05

Anti-Stripping Agent

It is well known that asphalt pavements exposed to moisture can have quality issues related to the loss of adhesion between aggregate and asphalt binder film (stripping) and cohesion within the asphalt binder (softening). Most often, the stripping of pavement begins at the bottom of the asphalt pavements and progresses upward, resulting in fatigue cracking. Therefore, the mitigation of moisture susceptibility of asphalt mixtures has an important role in the long-term quality management of asphalt pavements.

Anti-stripping agents such as hydrated lime (i.e., addition of aggregate as a slurry) or chemical additives (i.e., surfactants that are often added to the asphalt binder at the refinery or terminal) are widely used to enhance asphalt-aggregate adhesion and reduce the moisture-induced damage potential of associated mixes. Specifically, an anti-stripping agent can reduce the surface tension and increase the wettability of aggregates, which produces better adhesion between the asphalt binder and the aggregate surface. Asphalt mixtures that have an anti-stripping agent should meet the required tensile strength ratio (TSR) specified in accordance with AASHTO T 283 [76].

Christensen reported that the cost/benefit analysis indicated that the mandatory use of antistrip—regardless of the outcome of moisture resistance testing—would probably result in significant savings to the lifecycle cost [77]. Since Dec. 30, 2016, all JMFs (HMA and WMA) have been required to contain a minimum dosage of anti-strip additives (manufacturer recommended dosage, typically more than 0.25% by mass of asphalt content) to improve durability. If the WMA technology includes an anti-strip additive, an additional liquid antistrip additive is not required in mixtures where the moisture sensitivity analysis cannot be performed. If needed, PennDOT recommends use of either a compatible, heat stable, amine-based liquid anti-strip or a compatible alternate anti-strip additive as provided in Section 413.2(e). If the WMA technology includes an anti-strip additive as part of its WMA technology, perform moisture susceptibility analysis as specified in Section 413.2(e)1 and add additional anti-strip additive or make other adjustments to the JMF if needed to meet the specified moisture susceptibility requirements.

Cold Weather Paving and Compaction

Cold weather paving is usually limited due to potential pavement quality issues. In case of HMA, as air temperature decreases, it can cool down rapidly and the time available for compaction is significantly reduced. Poorly compacted pavements will have sparse inter-particle distance, resulting in a less stable and highly permeable structure. Compacting HMA pavements on a frozen base results in two problems: more rapid cooling will prevent adequate compaction and a wet, thawed base can cause support failure. If the frozen base contains moisture, the temperature drop is even greater [78]. On the other hand, it has been reported that WMA can be utilized to improve compaction and enable longer hauling times and distances in cold weather temperatures and conditions [74].

According to Section 413.3(b), the placement of asphalt mixture is limited within a specific season range unless an extension of the paving season is approved. For all PG 64E-22 wearing courses, >10-million-ESALs wearing courses, 4.75-mm wearing courses, or other wearing courses placed at compacted depths less than 1.5 inches, paving may occur April 1 to October 15. For all other courses, paving may occur April 1 to October 31. If the extension of paving season is approved, for all PG 64E-22 wearing and binder courses, >10-million-ESALs wearing courses, 4.75-mm wearing courses, or other wearing courses placed at compacted depths less than 1.5 inches, paving may occur April 1 to November 15. For all other courses, paving may occur March 1 to December 15. To maintain the temperature of asphalt mixtures, use of a material transfer vehicle (MTV) as specified in Section 108.05(c)5 is recommended when the paving length exceeds 1,500 linear ft. The information on hauling equipment is provided in 413.3(d).

For placement of the mix at SR 1016, as can be seen in **Table 15** (Exhibit R), a drastic decrease of temperature was observed during November 2019. The average temperature was sometimes less than 30 °F, which can cause a significant temperature decrease in the asphalt mat, resulting in a compaction issue. It can be concluded that a restriction of asphalt paving in cold weather is needed to mitigate the asphalt quality issue.

It was found that for some of the sublots the density of asphalt mixtures at SR1016 and SR2020 did not meet the density requirement, which might be attributed to the cold weather paving. Kim et al. [79] reported that temperature segregation of HMA and WMA mat can cause potential asphalt pavement quality issues related to air voids, density, rutting resistance, and stiffness. Thermal segregation is caused by a non-uniform temperature distribution of uncompacted asphalt mixtures. In the research by Kim et al., an infrared thermography system was used to record temperatures of uncompacted asphalt mat. Their report indicated that the exposure of WMA to cold weather increased vulnerability to the temperature segregation issue.

In addition, sufficient compaction is important for cold weather paving to achieve target asphalt density and air voids. Localized areas of poor compaction are expected to accelerate pavement distresses. Because of poor condition of the existing waterline at SR 1016 and SR 2020, compaction was limited (non-vibratory rolling request in Exhibit H and I and rolling pattern request in Exhibit J), which may result in decreased density issue. A limitation of compaction can cause a formation of less dense structure having a large inter-particle space, resulting in a low density as well as poor supporting and bearing capacity. This might also be vulnerable to asphalt surface cracking.

Table 15. Average temperature of Wilkes-Barre in a period of extended asphalt paving (from [11])

Date	Avg Temp (°F)	Date	Avg Temp (°F)	Date	Avg Temp (°F)
10/1/2019	69.2	10/22/2019	57.6	11/12/2019	29.5
10/2/2019	73.3	10/23/2019	53.0	11/13/2019	22.5
10/3/2019	55.8	10/24/2019	52.5	11/14/2019	31.5
10/4/2019	53.9	10/25/2019	52.0	11/15/2019	36.1
10/5/2019	48.3	10/26/2019	54.0	11/16/2019	33.1
10/6/2019	60.3	10/27/2019	59.7	11/17/2019	32.0
10/7/2019	59.0	10/28/2019	59.6	11/18/2019	37.1
10/8/2019	55.4	10/29/2019	56.1	11/19/2019	40.7
10/9/2019	53.9	10/30/2019	59.6	11/20/2019	40.4
10/10/2019	57.9	10/31/2019	67.6	11/21/2019	45.2
10/11/2019	55.1	11/1/2019	45.5	11/22/2019	44.2
10/12/2019	52.9	11/2/2019	41.0	11/23/2019	35.5
10/13/2019	53.6	11/3/2019	40.1	11/24/2019	36.8
10/14/2019	54.9	11/4/2019	44.0	11/25/2019	41.2
10/15/2019	50.4	11/5/2019	50.0	11/26/2019	43.4
10/16/2019	56.2	11/6/2019	44.0	11/27/2019	49.9
10/17/2019	49.0	11/7/2019	40.6	11/28/2019	39.8
10/18/2019	-	11/8/2019	28.9	11/29/2019	30.9
10/19/2019	-	11/9/2019	29.8	11/30/2019	32.3
10/20/2019	-	11/10/2019	41.4		
10/21/2019	58.3	11/11/2019	45.8		

Other Areas of Improvements in Asphalt-Related Specifications

The asphalt pavements constructed on SR 2016 and SR 2020 were governed by Change 5 of PennDOT Construction Specification 2016 Edition (Pub 408). There have been several significant changes since 2016 to produce the latest version of Publication 408 (2020 Edition, Change 2). These changes include:

- Significant change to weather limitations and extended season paving – Change 6, April 2019
- Requiring paint of existing vertical surfaces in contact with bituminous mixtures with uniform coating of PennDOT Materials Class TACK or NTT/CNTT – Change 7, October 2019
- Creating the new Section 313 for asphalt base mixes through merger of Sections 309 (Hot Mix Asphalt Base) and 311 (Warm Mix Asphalt Base) – Initial Edition, 2020
- Creating the new Section 413 for asphalt surface mixes through merger of Sections 409 (Hot Mix Asphalt Wearing Course) and 311 (Warm Mix Asphalt Wearing Course) – Initial Edition, 2020

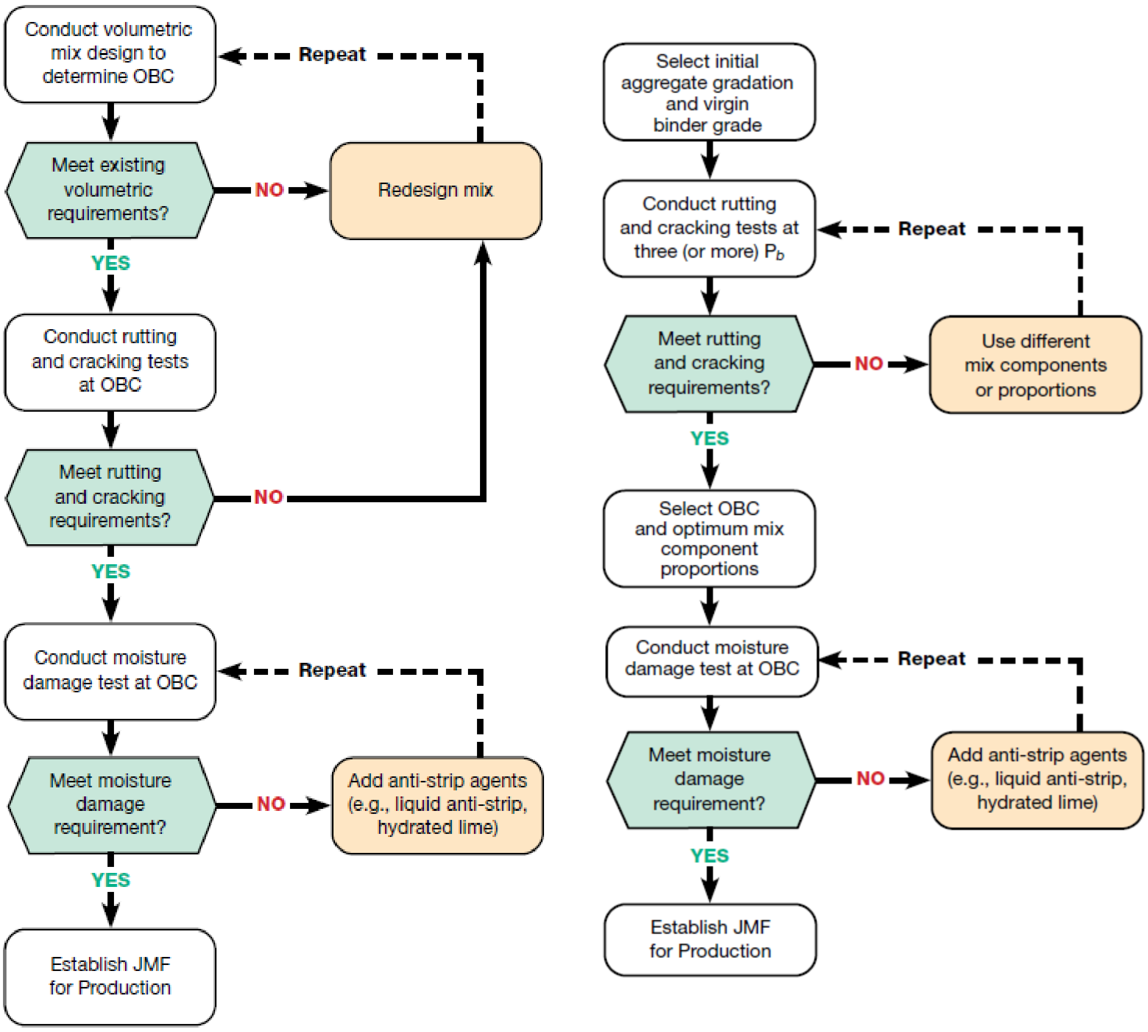
In the path forward, there are several areas that PennDOT may consider in making improvements to asphalt-related specifications. Some of these important areas include:

- Engineered Balanced Mix Design:
  PennDOT has already been moving toward balanced mix design (BMD) and several pilot projects have been placed in some districts within the last few years. PennDOT is continuing this effort and intends to place more performance-based designed mixes during the next several construction seasons. These efforts are highly encouraging and should continue at a fast pace so that relevant and reliable accept/reject criteria can be established for the mix performance tests that are used in connection with the balanced mix design. NAPA Balanced Mix Design Resource Guide (S-143) [80] and AASHTO PP 105-20 [81] are useful guides for this purpose. The NAPA guide identifies four approaches to BMD: (1) Volumetric Design with Performance Verification, (2) Volumetric Design with Performance Optimization, (3) Performance-Modified Volumetric Design, and (4) Performance Design. The flow chart in **Figure 16** presents approaches (1) and (4), which respectively indicate the design with the least and most level of effort.

  The most common approach used by some states, including Pennsylvania, is the first approach (Volumetric Design with Performance Verification). Here, the mix is first designed based on volumetric design criteria and then verified through performance testing to ensure adequate resistance to rutting and cracking. If adequate resistance is not met, the mix is redesigned. In approach (4), initial aggregate gradation and virgin binder grade are selected, and mixes are prepared at three or more different asphalt contents and performance tests are conducted for all. Obviously, this approach is labor intensive and requires a significantly larger amount of performance testing compared with the first approach. It may be prudent to use approach (4) for extreme traffic levels and projects with extensive investment.

- Assessing the Tack Bond Strength:
  Cold weather paving sometimes creates an obstacle in getting a well-bonded tack coat. The colder weather reduces the curing rate of the emulsion-based tack coat and in that respect, it is best to avoid use of slow-setting tack coat in cold season paving. Because of the concern with proper bond, it is best if specifications require testing the bond according to existing established protocols to ensure sufficient strength has developed at the interface between the layers.

- Reduce Potential for Thermal Segregation:
  Cold paving increases the potential for mix thermal segregation, which subsequently can result in physical segregation and loss of density. Specifications already require use of heated or insulated trucks to reduce this problem. An additional improvement could include requiring measurement of the mat temperature either at frequent random spots or through use of infrared sensors to cover temperature within the mat area.



(a) (b)

Figure 16. Graphical illustration of volumetric design with performance verification approach: (a) Volumetric Design with Performance Verification and (b) Performance Design Approach (from [80])

- Inclusion of higher RAP content in asphalt mixes and revising specifications to consider reclaimed asphalt binder ratio (RBR) rather than the RAP content [82]:
  PennDOT currently limits the recycled asphalt materials (e.g., RAP and recycled asphalt singles, also known as RAS) RAP and RAS content due to potential stiffness, workability, and ductility issues. However, this approach cannot account for the effective binder content. According to NCHRP Report 752 [83], use of RBR is more recommended, which is a ratio of reclaimed binder from RAP and RAS to total percent of binder in asphalt mixture. Because the RBR can describe the effective binder content in the asphalt, this ratio is better than specification of maximum allowable RAP and RAS content.

- Inclusion of recycling agents with asphalt mixes containing high RAP or RAS [84]:
  Recycling agents have been used to restore aged binder. Recycling agents can be categorized into two groups: softening agent (reduction of viscosity of asphalt binder) and rejuvenators (restoration of chemical balance and rheological properties of binder). When recycling agents are added in asphalt mixtures, the improvement of cracking

resistance and reduction of rutting resistance were observed. However, more investigations are still needed due to variations of results caused by types of recycling agent, RAP, RAS, binder, and their compatibility.

- Inclusion of other recycling materials such as plastics [85]:
  As the issue of waste plastic in the United States has been addressed, the recycling/upcycling of plastic (e.g., low- and high-density polyethylene and polypropylene) into asphalt mixtures has been investigated. In the aspect of performance of asphalt pavements, the recycled plastic modified (RPM) asphalt may be beneficial for increasing service life and reduction in needs for polymers to modify asphalt binders. However, more research will be needed to determine feasibility of use, optimum dosage of plastic, mixing criteria and procedure, compatibility, and stability of plastic in asphalt.

- Considering revisions to gyrations levels (laboratory compaction) for different traffic levels and possibility of using the same gyration level for all mixes [86]:
  In the Texas Department of Transportation (TxDOT) Special Specification 3074: Superpave Mixtures – Balanced Mix Design, all surface mixtures are required to meet the existing volumetric requirements as well as performance test requirements. The design air voids content is 4.0 percent at a N_{design} of 50 gyrations for all traffic levels. Some states including Pennsylvania are considering limiting the number of gyration levels to one or two.

2.6 Chapter Summary

Based on a review of the current PennDOT Construction Specifications in comparison with the state of knowledge and national standards, the following conclusions can be drawn related to the design and construction of concrete sidewalks:

- Mitigation of the scaling risk in concrete sidewalks starts with design and selection of a good quality dense concrete mixture that has a low w/cm (< 0.47 and preferably < 0.45), proper slump (< 5 inches), and adequate entrained air (6% target).

- If reactive aggregates are present, a sufficient SCM dosage to mitigate ASR must be used. However, excessive SCM quantities must be avoided, as they lead to significant delays in setting and strength development of concrete, especially in cool and cold weather construction seasons. These fresh-state and early-age effects increase the risk of surface scaling of concrete. For construction with concrete containing SCM, contractors must develop a plan to be approved by PennDOT to make sure that proper finishing and curing of concrete will not be compromised.

- To mitigate scaling, good construction, finishing, and curing practices for concrete are also critical. Concrete must be placed in molds and properly consolidated but not over-vibrated. After floating, any additional finishing (such as edging, jointing, smoothing, and texturing) must wait until after the concrete has passed initial setting, bleeding has completed, and the bleed water has evaporated or has been removed using a hose drag. Any finishing operations performed while the concrete is still bleeding will result in later problems, such as dusting, scaling, crazing, delamination, and blisters.

- Excessive finishing and smoothing of sidewalk surfaces are not needed and increase the scaling risk. Air-entrained concrete should not be troweled. Use of Fresno and power trowels must be avoided. Intricate finishing operations that require excessive hand-finishing must be avoided if possible.

- Reworking of bleed water into the surface or adding water to make finishing easier (a practice known as "blessing" the concrete) result in a weak and high-porosity surface that is prone to scaling and cracking. These practices must be absolutely avoided.

- Concretes with slow setting, such as those containing SCMs, may bleed slowly and for a long time. On dry and windy days, the bleed water evaporates rapidly, and the surface may dry out before the concrete has begun initial setting and is ready for finishing and curing. This creates a high risk for plastic shrinkage cracking. In such cases, an evaporation retarder such as a monomolecular film must be sprayed over the surface. Finishing the concrete before initial setting can trap the residual bleed water near the surface layer, resulting in increased scaling risk.

- Appropriate curing is also critical to ensure that concrete achieves its full potential and to reduce the scaling risk. Curing for 7 days using liquid membrane-forming curing compounds or water curing as specified in Section 1001.3(p) of Specifications should be employed. Curing must be commenced immediately after finishing. Care must be taken to make sure the exposed concrete surfaces never dry out. If curing is delayed for any reason, an intermediate monomolecular film curing agent must be applied to protect the surface.

- After conclusion of curing, application of a breathable sealer (e.g., silane, siloxanes, or boiled linseed oil) is recommended to protect the concrete from deicing salt scaling. The sealer creates a protective barrier to minimize penetration of water and deicing chemicals into concrete. Generally, sealants with solid contents of 25% or higher are recommended.

- Using deicing chemicals within the first few months after construction of concrete sidewalks is discouraged. Instead, clean sand should be used for traction. Deicing chemicals composed of calcium chloride and sodium chloride (rock salt) are acceptable for concrete but ammonium sulfate, ammonium nitrate, or magnesium-based salts must be avoided, as they are chemically aggressive and harmful to concrete surfaces.

The following conclusions relate to construction of high-quality asphalt pavements and issues related to the pavements on SR 1016 and SR 2020:

- The asphalt mix placed on SR 1016 and SR 2020 was from an approved mix design using warm-mix technology and included PG 64-22 binder with 20 percent reclaimed asphalt pavement. The mix design satisfied all PennDOT bulletin 27 requirements [60]. According to Bulleting 27, when the RAP content exceeds 15%, the performance grade of the RAP asphalt binder must be extracted and its performance grade determined. While this process most probably has been conducted, the information on the RAP binder performance grade and the final performance grade of the blended binder were not found in the reviewed documents. In Chapter 1, it was discussed that the likely cause of the density and segregation problems observed on these two roads was due to cold weather paving and thermal segregation, but no temperature data were available to substantiate this assessment.

- The PennDOT specifications were compared to determine the level of changes that have occurred since placement of the asphalt mixes on SR 1016. Comparing Specification 408, Section 409, Change No. 5 (which was the governing specification for placement of asphalt mixes at SR 1016 and SR 2020) with the most recent Specification 408/2020-2 indicates that the significant specification changes during this time frame have included merger of sections 409 and 411 and changing the extended season paving requirements. The requirements for cold season paving have remained similar between these two specifications. The additional requirement in the 2020 edition is conducting spring evaluation of distresses for the mix placed in the extended season. This additional requirement is an improvement over the original language used in the 2016 edition because it provides PennDOT with the leverage of evaluating the quality of the material placed in the extended paving season shortly after placement. Other requirements to ensure quality paving in cold weather are similar and properly covered in both specifications. These include use of the material transfer vehicle and use of double-walled truck body or heated truck.

- Improvements could be made to existing PennDOT asphalt specifications in several areas based on national research findings. These include:
    - Balanced mix design and performance-based testing;
    - Assessing the tack bond strength;
    - Reducing potential for thermal segregation;
    - Inclusion of higher RAP content in asphalt mixes and revising specifications to consider reclaimed asphalt binder ratio (RBR) rather than the RAP content;
    - Inclusion of recycling agents with asphalt mixes containing high RAP or RAS;
    - Inclusion of other recycling materials such as plastics; and
    - Considering revisions to gyrations levels (laboratory compaction) for different traffic levels and the possibility of using the same gyration level for all mixes

- Performance-based specifications using balanced mix design and performance-based testing have gained considerable momentum within the last few years and PennDOT is seriously considering such specifications. It is recommended that PennDOT continue this effort at an expeditious pace. Use of performance tests with pavement cores is especially important with cold paving, as the chances of pavement problems increase when the mix is placed at cold temperatures.

Chapter 3. Review of Pertinent Specifications in Six Other States

3.1 Introduction

This chapter provides a comparison of previously identified PennDOT Specifications sections with pertinent concrete and asphalt specifications of state highway agencies in Michigan, Minnesota, North Carolina, Texas, Virginia, and Wisconsin. The specific sections within the latest version of each DOT specifications are listed below:

- Michigan DOT Standard Specifications for Construction, 2012 Edition [87]
  - Section 501 Plant Produced Hot Mix Asphalt
  - Section 601 Portland Cement Concrete for Pavements
  - Section 701 Portland Cement Concrete for Structures
  - Section 803 Concrete Sidewalks, Sidewalk Ramps, and Steps

- Minnesota DOT Standard Specifications for Construction, 2018 Edition [88]
  - Section 2360 Plant Mixed Asphalt Pavement
  - Section 2521 Walks
  - Section 2461 Structural Concrete

- North Carolina DOT Standard Specifications for Roads and Structures, 2018 Edition [89]
  - Section 420 Concrete Structures
  - Section 610 Asphalt Concrete Plant Mix Pavements
  - Section 848 Concrete Sidewalks, Driveways and Curb Ramps
  - Section 1000 Portland Cement Concrete Production and Delivery

- Texas DOT Standard Specifications for Construction and Maintenance of Highways, Streets, and Bridges, 2014 Edition [90]
  - Item 531 Sidewalks
  - Item 421 Hydraulic Cement Concrete
  - Item 341 Dense-Graded Hot-Mix Asphalt

- Virginia DOT Road and Bridge Specifications, 2020 Edition [91]
  - Section 211 Asphalt Concrete
  - Section 217 Hydraulic Cement Concrete
  - Section 504 Sidewalks, Steps, and Handrails

- Wisconsin DOT Standard Specifications for Highway and Structure Construction, 2021 Edition [92]
  - Section 460 Hot Mix Asphalt Pavement
  - Section 501 Concrete
  - Section 602 Concrete Sidewalks, Loading Zones, Safety Islands, and Steps

Additionally, a survey of the State Materials Engineers and the State Construction Engineers within the above DOTs was performed to inquire about relevant current issues that each DOT is facing as well as their design and construction specifications for concrete sidewalks and asphalt pavements. A similar survey was completed by PennDOT. Lessons learned and recommendations based on the above review and survey are provided within this chapter.

3.2 Concrete Sidewalks - Comparison of PennDOT Specifications with Those of the Six Other States

Based on the conclusions of Chapter 2, concrete mix design parameters as well as construction and curing practices are significant in determining the susceptibility of concrete flatwork, including pavements and sidewalks, to deicing salt scaling. Among concrete mix design parameters, water to cementitious materials mass ratio, dosage of supplementary cementitious materials, air content, and slump are the most significant. Timing of construction operations in comparison with time of setting of concrete is also important. For example, placement, consolidation, strike-off, and bull-floating must be performed prior to initial setting of concrete. Any additional finishing (such as edging, jointing, smoothing, and texturing) must wait until after concrete has passed initial setting, bleeding has completed, and the bleed water has evaporated or has been removed using a hose drag. Reworking of bleed water into concrete surface or adding water to make finishing easier must be strictly avoided. Appropriate curing is also critical to ensure that concrete achieves its full potential and to reduce the scaling risk. Curing for 7 days using liquid membrane-forming curing compounds or water curing should be employed. Curing must be commenced immediately after finishing. Care must be taken to make sure the exposed concrete surfaces never dry out.

Table 16 and **Table 17** provide a summary and comparison between the latest version of PennDOT specifications governing the design and construction of sidewalks with the current specifications from state DOTs in Michigan, Minnesota, North Carolina, Texas, Virginia, and Wisconsin. Further details on the specifications in each of these six states are described after the tables.

The main items of difference among the specifications of PennDOT and the six other states pertaining to design and construction of concrete sidewalks are listed below:

- Max. w/cm:
  While PennDOT specifications limit w/cm to less than or equal to 0.50, other states specify the max. w/cm as low as 0.44 to as high as 0.60. Generally, states with a climate similar to or colder than Pennsylvania have a low max. w/cm. For example, Minnesota specifies $(w/cm)_{max}$=0.45 while Wisconsin specifies $(w/cm)_{max}$=0.44 for concrete containing fly ash and $(w/cm)_{max}$=0.47 for all other concrete.

- Max. SCM dosage:
  While PennDOT allows up to 35% fly ash and up to 65% slag, other states generally limit the SCM dosage at lower levels. For example, Minnesota allows up to 25% fly ash and up to 30% slag. Wisconsin allows up to 30% fly ash or slag. Other states limit the slag content to 50% max.

- ASR mitigation protocols vary among the states.

- Max. slump:
  While PennDOT allows up to 8 inches of slump with the use of high-range water reducers, other states specify lower allowable slumps. For example, North Carolina and Wisconsin do not allow slump higher than 4 inches.

- Minimum compressive strength:
  Most states have a minimum 28-day compressive strength of 2,500 to 3,500 psi while Minnesota requires a 4,500 psi concrete at 28 days.

- The required curing period varies between 3 and 7 days among different states.

Table 16. Specification requirements on mix design for concrete sidewalks

DOT Specs.	w/cm range	Cementitious material factor	SCM range	ASR mitigation protocol	Target slump	Target air content	Compressive strength
PennDOT Pub 408, 2020 Change 2 (Sec 676)	Max. 0.50 Class A concrete to be used for sidewalks (704)	564–752 lb/yd³ (704)	Determined based on ASR mitigation requirements. Max permissible SCM: Fly ash: 35% Slag: 65% Silica fume: 2.4 × cement factor × alkali content (704.1(g))	Similar to AASHTO R80	Max slump: w/o WR: 5” w/ WR 6 ½” w/ HRWR: 8” (704.1(c)4)	6.0% (704.1.(c)3)	Min. 2750 psi at 7 d Min. 3300 psi at 28 d
Michigan DOT 2012 (Sec 803)	None specified. Class P2, P1, S3, S2 concrete can be used for sidewalks (601, 701)	Min. 564 lb/yd³ for P1 and S2 Min. 517 lb/yd³ for P2 and S3 (601, 701)	SCM is not required for sidewalks	Focused on fine aggregates and use of ASTM C1260 and C1293 tests. SCM dosage is determined using ASTM C1567	w/o WR: 0-3” w/ WR: 0-6” or 0-7” (601.3)	5.0-8.5% (601.3, 701.03)	Min. 2200-2600 psi at 7 d Min. 3000-3500 psi at 28 d (601, 701)
Minnesota DOT 2018 (Sec 2521)	Max. 0.45 Class 3F52 concrete to be used for sidewalks (2461.2)	Max. 750 lb/yd³ (2461.2)	For sidewalks: Fly ash: Max. 25%, Slag: Max. 30% (2461.2-6)	Use appropriate dose of SCMs depending on degree of expansion of aggregates (2301.2)	2-5” (2461.2)	6.5% (2461.2F)	Min. 4500 psi at 28 d (2461.2)
North Carolina DOT 2018 (Sec 848)	Max. 0.488 (AE, round agg) Max. 0.567 (AE, angular agg) Max. 0.559 (non-AE, round agg) Max. 0.630 (non-AE, angular agg) Class B concrete to be used for sidewalks (1000-4)	Min. 508 lb/yd³ (vibrated) Min. 545 lb/yd³ (non-vibrated) (1000-4)	Fly ash: Max. 30%, Slag: Max. 50% Silica fume: Max. 8% (1000-4)	Alkali content of cement: Max. 1.0% When reactive aggregates are used with cement having an alkali content of 0.6-1.0%: use Class F fly ash: 20-30%, Slag: 35-50%, or Silica fume: 4-8% (1024-1)	Max. 1.5” (machine placed) Max. 2.5” (hand placed) Max. 4” (non-vibrated) (1000-4)	6.0% (1000-4)	Min. 2500 psi at 28 d (1000-4)

Table 16. Continued

DOT Specs.	w/cm range	Cementitious material factor	SCM range	ASR mitigation protocol	Target slump	Target air content	Compressive strength
Texas DOT 2014 (Sec 531)	Max. 0.60 Class A concrete to be used for sidewalks (421.4.1)	Max. 700 lb/yd³ (421.4.2.1)	Fly ash: Max. 35% Slag or modified F fly ash: Max. 50% Blended SCM: Max. 50% (421.4.2.6)	All aggregates are reactive, and a mitigation strategy must be used. TXDOT has 8 mix design option for ASR mitigation (SCM, limit alkali loading, etc)."	None specified	Min. 3.0% (421.4.2.4)	Min. 3000 psi at 56 d (421.4.2.1)
Virginia DOT 2020 (Sec 504)	Max. 0.49 Class A3 concrete to be used for sidewalks (217.06)	Min. 564 lb/yd³ (A3 general) (217.06)	Class F fly ash: Max. 30% Slag: Max. 50% Silica fume: Max. 10% (217.02)	**Total alkalis of cement: < 0.75%:** Fly ash: Min. 20% Slag: Min. 40% Silica fume: Min. 7% Metakaolin: Min. 7% **Total alkalis of cement: 0.75–1.0%:** Fly ash: Min. 25% Slag: Min. 50% Silica fume: Min. 10% Metakaolin: Min. 10% (217.02)	1-5" (217.06)	6.0% (217.06)	Min. 3000 psi at 28 d (217.06)
Wisconsin DOT 2021 (Sec 602)	Several classes of concrete can be used for sidewalks: Class A, A2, A-S, A-T, A-IL, A-IP, A-IS, A-IT* Max. w/cm=0.47 Class A-FA Max. w/cm=0.44 (501.3)	530 lb/yd³ for A2 565 lb/yd³ for A, A-FA, A-S, A-T, A-IL, A-IP, A-IS, A-IT (501.3)	Fly ash: 30% for A-FA, Slag: 30% for A-S Fly ash + slag: 30% for A-T (501.3)	When reactive coarse aggregates are used, the combination of aggregates and SCM is tested via ASTM C1567 and must produce expansion<0.15% at 14 days (501.2.5)	1-4" (501.3.7.1)	6.0% (501.3.2.4)	Not specified

*IL, IP, IS, IT are blended cement types specified in ASTM C595 [93]. Maximum content of SCM within the blended cement: 30% pozzolan for type IP, 30% slag for type IS, 10% limestone for type IL, and 10% limestone and 30% pozzolan and/or slag combined content for type IT.

Table 17. Specification requirements on construction of concrete sidewalks

DOT Specs.	Allowable ambient temperature	Concrete temperature at the time of placement	Finishing	Curing method	Curing duration
PennDOT Pub 408, 2020 Change 2 (Sec 676)	> 40 F (704.1(f))	50–90F (704.2(c))	Machine or manual strike-off and consolidation, followed by floating and a final broom finish. (676)	Water curing (by polyethylene sheeting, or wet burlap) or use of liquid membrane-forming curing compound (711.1 and 711.2)	7 days wet cure or curing compound (1001.3)
Michigan DOT 2012 (Sec 803)	> 40F (601.04, 701.04)	45-90F (602.03)	Consolidation of concrete, followed by floating and final finishing with coarse broom (803)	Membrane forming curing compound (602.03)	Sidewalks: Curing comp. Bridge decks: 7 day wets cure (602.03)
Minnesota DOT 2018 (Sec 2521)	> 36F (2461.3)	50-90F (2461.3)	Consolidation of concrete and strike-off concrete, followed by floating and brushing (2521.3)	Wet burlap, membrane curing compound, plastic curing blanket (polyethylene sheeting) (3751)	Not specified
North Carolina DOT 2018 (Sec 848)	> 35F (1000-4 D)	50-95F (1000-4 D)	Strike off and compact, followed by finishing with a float, trowel smooth, and broom (825-6)	Membrane forming curing compound, polyethylene film, wet burlap (700-9)	3 days w/o SCM 7 days w/ SCM (825-8)
Texas DOT 2014 (Sec 531)	> 40F (420.4.7.11)	> 50F (420.4.7.11)	Placement and consolidation of concrete, followed by hand finishing and application of a uniform transverse broom (531)	Membrane forming curing compound, polyethylene sheeting, wet burlap (420.2.7)	3 days (531)
Virginia DOT 2020 (Sec 504)	> 40F (surface of concrete) (316.04)	40-95F (217.10)	Smooth with a wooden float, final finishing with hand float, light brooming and light metal marking rollers can be followed (504)	Membrane forming curing compounds Polyethylene film (316.04)	5 days (504.03)
Wisconsin DOT 2021 (Sec 602)	> 40F (502.3.9)	50–80F (502.3.9.2)	Consolidation, strike-off and finishing with brush or lightly broom (602.3.2.3)	Liquid curing compound (415.3.12)	4 days for Class A, A2 5 days for Class A-FA, A-IP, A-IT 7 days for A-S, A-IL, A-IS, A-T (415.3.15)

Michigan DOT (MDOT)

The current MDOT specifications are the 2012 edition. A draft version of the 2020 edition is available online. In MDOT specification 2012, the requirements for concrete sidewalks are specified in Sections 601, 701, and 803. Concrete mixtures (Class P1 and P2 for concrete pavements and Class S2 and S3 for concrete structures) can be applicable for concrete sidewalk purposes.

No w/cm requirement is specified for class P1, P2, S2, and S3 concretes. The maximum cement factor is 564 lb/yd^3 for P1 and S2 and 517 lb/yd^3 for P2 and S3. The slump ranges are varied depending on the type of water-reducing admixture (WRA) used: Type A water reducing, Type D water reducing and retarding, Type F high range water reducing, Type G high range water reducing and retarding according to ASTM C494 [94]. In Section 701, slump ranges for S2 and S3 concrete are 0–3 inches with Type A, Type D, or with no WRA. Slump ranges are 0–6 inches with mid-range WRA, and 0–7 inches with Type F or Type G admixtures. Slump requirements for P1 and P2 are not specified. The target air content of fresh concrete is in the range of 5.0–8.5% for P1 and P2 and 5.0–8.0% for S2 and S3 mixtures. Compressive strength requirements are 2,600 psi at 7 days, 3,000 psi at 14 days, and 3,500 psi at 28 days for P1 and S2; and 2,200 psi at 7 days, 2,600 psi at 14 days, and 3,000 psi at 28 days for P2 and S3.

According to MDOT 2012 specifications, concrete for sidewalks and curbs is not required to contain SCMs. However, MDOT responses to the Penn State survey indicate mandating the use of 25-40% SCM by mass of cementitious materials for pavements and structural concrete. MDOT requires testing the reactivity of fine aggregates according to ASTM C1293 or ASTM C1260 and determining the sufficient dose of SCM (within the range 25-40%) to mitigate ASR according to ASTM C1567.

At the time of concrete placement, concrete temperature must be in a range of 45 °F–90 °F as specified in Section 601 of MDOT specifications. After the construction of concrete sidewalks, pedestrian traffic is allowed after 48 hours. In a cold weather construction, the local average minimum temperature for the next consecutive days after concrete placement must be higher than 40 °F. After placement, concrete sidewalks should be cured as soon as the free water leaves the surface. The surface of concrete should be coated with a uniform layer of membrane-forming curing compound. The application rate is at least 1 gal per 25 yd^2 of surface for each coat. A second coat should be sprayed within 2 hours. It is recommended to allow pedestrian traffic after 48 hours.

Minnesota DOT (MNDOT)

The current MNDOT specifications are the 2018 edition. The 2020 edition is also available online and is effective on August 27, 2021. In the 2018 MNDOT specification, the requirements for concrete [side]walks are specified in Sections 2521 and 2461. Concrete class 3F52 is allowed for concrete walks. As provided in Section 2461, 3F52 concrete for flatwork has a maximum w/cm of 0.45, maximum cementitious content of 750 lb/yd^3, maximum percentage of fly ash (25%) and slag (30%), slump range of 2–5 inches, and minimum 28-day compressive strength of 4,500 psi. If concrete contains reactive aggregates, ASR should be mitigated using SCMs as specified in **Table 18** and **Table 19**. Note that the MNDOT specifications place a maximum allowable SCM for sidewalks at 25% fly ash or 30% slag, according to Table 2461.2-6.

Table 18. ASR mitigation requirements for fine and intermediate reactive aggregates (MNDOT Section 2301.2 Table 2301-2)

14-day fine and intermediate aggregate expansion limits (ASTM C1260)	Class F fly ash	Class C fly ash	Slag	Ternary (maximum of 40%)			
				Slag/Class F fly ash	Slag/Class C fly ash	Type IS(20)/ Class F fly ash	Type IS(20)/ Class C fly ash
≤ 0.150	No mitigation required						
0.15–0.20	Min. 20%	Min. 20%	35%	20% slag with a minimum of 15% Class F fly ash	20% slag and 20% Class C fly ash	Type IS(20) blended cement plus minimum of 15% Class F fly ash	Type IS(20) blended cement plus a minimum of 15% Class C fly ash
0.20–0.30	Min. 20%	Min. 30%	35%				
> 0.30	The MNDOT will reject the fine aggregate						

Table 19. ASR mitigation requirements for coarse reactive aggregate (MNDOT Section 2301.2 Table 2301-3)

ASTM C1293 expansion	Class F fly ash	Class C fly ash	Slag	Slag/Class F fly ash	Slag/Class C fly ash	IS(20)/ Class F fly ash	IS(20)/ Class C fly ash
≤ 0.04	No mitigation required						
> 0.04	Min. 30%	Not allowed	35%	20% slag with a min. of 15% Class F fly ash	20% slag and 20% Class C fly ash	Type IS(20) with a min. of 15% Class F fly ash	Type IS(20) with a min. of 15% Class C fly ash

The temperature of concrete mixtures at the time of placement should be in a range of 50–90 °F and this temperature range needs to be maintained until concrete is properly deposited. The appropriate temperature of aggregate is in a range of 32–130 °F before mixing. For finishing of concrete walks after the placement, at least two people, having a current ACI concrete flatwork technician certificate, are needed. For consolidation, internal vibration can be used. After completing the final finishing, curing and protection of the surface are needed within 30 minutes of concrete placement or once the bleed water is dissipated. When membrane-curing compounds (e.g., poly-alpha methylstyrene (AMS) or linseed oil membrane-curing compounds) are used, they should cover the surface area at a minimum rate of 1 gal/ft^2. In case of curing blankets, the surface of concrete walks is covered by the blanket, which can prevent loss of water vapor. After the conclusion of curing using blankets the surface of concrete must be properly sprayed with a membrane-curing compound. The surface of concrete walks should be protected against rain or cold weather. When the air temperature is less than 36 °F within the first 24 hours after construction, a cold weather protection plan from damage (e.g., freezing due to cold weather) is needed.

North Carolina DOT (NCDOT)

In the NCDOT specification 2018, the requirements for concrete sidewalks are specified in Sections 848 and 100-4. Class B concrete should be used for concrete sidewalks. The maximum w/cm for Class B concrete is varied depending on the presence of air entrainment (AE) and/or shape of aggregate: 0.488 for AE concrete having rounded aggregate, 0.567 for AE concrete having angular aggregate, 0.559 for non-AE concrete having rounded aggregate, and 0.630 for non-AE concrete having angular aggregate. The minimum cementitious material contents are varied: 508 lb/yd^3 when concrete is vibrated, and 545 lb/yd^3 without vibration.

The air content in the freshly mixed concrete should be in a range of 6.0 ± 1.5%, which can be determined in accordance with AASHTO T 152 and AASHTO T 196 [95,96]. The maximum slump for Class B concrete varies: 1.5 inches when the concrete is machine placed, 2.5 inches with hand placement, and 4.0 inches when the concrete is not vibrated. The compressive strength of Class B concrete should be higher than 2,500 psi at 28 days.

For mitigation of ASR, use of SCMs is required. The maximum allowable alkalinity of portland cement (Na_2O_{eq}) is 1.0%. SCMs are not required, but are allowed, if the concrete aggregates are non-reactive or if alkali content of the cement is less than 0.6%. Meanwhile, concrete incorporating cement with alkali content of 0.6–1.0% and reactive aggregate is required to use 20% to 30% Class F fly ash, 35% to 50% slag, or 4% to 8% microsilica (silica fume) as specified in Section 1024-1.

The construction of concrete sidewalks is specified in section 825 of NCDOT specifications. The temperature of concrete at the time of placement should be in the range 50–95 °F. Curing (e.g., via membrane-curing compound, polyethylene film, or wet burlap) must start immediately after finishing operation to prevent evaporation of surface water. In case of membrane-curing compound, it should be used at a minimum application rate of 0.0067 gal/ft^2 with machine spraying and 0.01 gal/ft^2 with hand spraying. If the concrete surface receives heavy rainfall, reapplication of curing compound is needed within 3 hours after initial application. In case of polyethylene film, the film must cover the entire finished concrete surface. Depending on the daily ambient temperature, black or dark plastic sheets (40–60 °F) or white opaque reflective plastic sheet (higher than 60 °F) should be used. Similarly, wet burlap should cover the finished pavement surface. Burlap needs to be saturated before placing of concrete and be kept wet during the curing period. In a cold weather construction, the air temperature should be higher than 35 °F. If air temperature is less than 35 °F, the aggregate and water should be preheated to less than 150 °F. The temperature of heated concrete should be 55–80 °F at the time of placement. Concrete exposed to cold weather (35 °F) should be protected with heated enclosure or insulation as specified in 420-7. Heated enclosure is needed to maintain air temperature surrounding concrete in a range of 50–90 °F for 72 hours after placement of concrete. In case of insulation, the air temperature under the insulation should be higher than 50 °F. The temperature surrounding the concrete during the protection period should be recorded using a thermometer. It should be noted that concrete containing fly ash or slag should be cured for at least 7 days. Otherwise, at least 3 curing days are required.

Texas DOT (TXDOT)

In the TXDOT specification 2014, the requirements for concrete sidewalks are specified in Sections 531 and 421. Class A concrete should be used for the construction of concrete sidewalks. Class A concrete should meet the requirements: maximum w/cm ratio of 0.60 and maximum cementitious material content of 700 lb/yd^3. Design strength of concrete is at least 3,000 psi within 56 days. The minimum entrained air content of concrete is 3.0%. There is no limit on the slump of concrete at the time of placement.

According to TXDOT's response to the Penn State survey, all aggregates are considered ASR reactive, and a mitigation strategy must be used. There are 8 mix design options for ASR mitigation as specified in Section 421:

(1) Replace 20% to 35% of the cement with Class F fly ash.
(2) Replace 35% to 50% of the cement with slag cement or modified Class F fly ash (MFFA).
(3) Replace 35% to 50% of the cement with a combination of Class F fly ash, slag cement, MFFA, ultra-fine Class F fly ash (UFFA), metakaolin, or silica fume; however, no more than 35% may be fly ash, and no more than 10% may be silica fume.
(4) Use Type IP, Type IS, or Type IT cement for each class of concrete. Up to 10% of a Type IP, Type IS, or Type IT cement may be replaced with Class F fly ash, slag cement, or silica fume. Use no more than 10% silica fume in the final cementitious material mixture if the Type IT cement contains silica fume, and silica fume is used to replace the cement.
(5) Replace 35% to 50% of the cement with a combination of Class C fly ash and at least 6% of silica fume, UFFA, or metakaolin. However, no more than 35% may be Class C fly ash, and no more than 10% may be silica fume.
(6) Use a lithium nitrate admixture at a minimum dosage determined by testing conducted in accordance with Tex-471-A. Before use of the mix, provide an annual certified test report signed and sealed by a licensed professional engineer, from a laboratory on the Department's MPL, certified by the Construction Division as being capable of testing according to Tex-471-A.
(7) Ensure the total alkali contribution from the cement in the concrete does not exceed 3.5 lb/yd^3 of concrete when using hydraulic cement not containing SCMs, which can be calculated as Na_2O_{eq} in cement × cement content.
(8) Perform annual testing as required for any deviations from Options 1–5 or use mix design options depending on ASTM C1260-based tests [97].

It should be noted that MFFA is a non-blended or blended Class F fly ash produced by inter-grinding with or without other SCMs (e.g., fly ash, slag, natural pozzolans, etc.). UFFA is finely pulverized Class F fly ash. The requirements of strength activity index, fineness, and ASR expansion for MFFA and UFFA are specified in DMS-4610. In blended SCMs, percentages of fly ash and silica fume are limited up to 35% and 10%, respectively. It should be noted that if the cementitious material content is less than 520 lb/yd^3, Class C fly ash can be used instead of Class F fly ash.

Temperature of Class A concrete should be greater than 50 °F at the time of placement. After the placement of concrete, its surface should be finished to a uniform transverse broom finished surface. Finished surfaces should be cured for at least 72 hours using approved curing methods (e.g., membrane-curing compounds, cotton mats, polyethylene sheet, or wet burlap) specified in Section 420. Membrane-curing compounds must meet the requirements of ASTM C 309 Type 1-D or Type 2 Class A (see **Table 20**) [98]. In case of polyethylene sheeting, its thickness should be larger than 4 mils (0.004 inches). Only clear or opaque white sheeting must be used when the ambient temperature during the curing exceeds 90 °F. Burlap-polyethylene mats and burlap materials must comply with AASHTO M 182 [99], Class 3 (10 oz/yd^2). In a cold weather construction, the ambient temperature in the shade should be higher than 40 °F. The temperature at surface of concrete should be higher than 40 °F for 72 hours from the time of placement.

Table 20. Type of curing compound specified in ASTM C309-19

Liquid membrane forming compounds	
Type 1	Clear or translucent without dye
Type 1-D	Clear or translucent with fugitive dye
Type 2	White pigmented
Class of solids	
Class A	No restrictions
Class B	Must be a resin as defined in ASTM D883

Virginia DOT (VDOT)
In the VDOT specification 2020 edition, the requirements for concrete sidewalks are specified in Sections 504 and 217. Class A3 concrete must be used for sidewalks. Class A3 general purpose concrete should meet the following requirements: maximum w/cm = 0.49, target slump in the range of 1–5 inches, minimum cementitious materials factor = 588 lb/yd^3, and minimum design compressive strength = 3,000 psi at 28 days. For the mitigation of ASR, the required dosage of SCMs depends on the alkali content of cement and is specified in **Table 21**.

Table 21. Minimum SCM dosage to be used when concrete includes reactive aggregates; source: VDOT specification 2020

Mineral admixtures	**Minimum SCM dosage**	
	Total alkalis of cement is less than or equal to 0.75%	**Total alkalis of cement is great than 0.75% and less than or equal to 1.0%**
Class F fly ash	20%	25%
GGBF slag	40%	50%
Silica fume	7%	10%
Metakaolin	7%	10%

Class C fly ash or other SCMs can be used if the maximum mortar bar expansion of 0.15% at 56 days is not exceeded according to ASTM C227 test [100] and with using borosilicate glass as aggregate. The maximum percentages of SCMs are specified as 30% for Class F fly ash, 50% for slag cement, and 10% for silica fume (Sec. 217.02).

At the time of placement, the temperature of concrete should be between 40 °F and 95 °F. For sidewalk construction, concrete shall be placed and consolidated without causing segregation. The surface shall be brought to grade by screeding and straight edging. The surface shall be smoothed with a wooden float to produce a surface free from irregularities. The final finish shall be obtained with an approved hand float that will produce a uniform surface texture. The concrete should be cured using membrane-forming curing compounds or by polyethylene film as specified in section 316.04. The curing compound should be applied at a constant dose of 100–150 ft^2/gal. In case of polyethylene film, white or clear films (only for November 1–April 1) can be used. Sidewalks should not be opened to pedestrian traffic for the first 5 days. During cold weather construction, the surface temperature of concrete sidewalk should be higher than 40 °F during the first 72 hours after concrete placement. To maintain concrete at the required temperature, water and aggregate can be heated up to 150 °F.

Wisconsin DOT (WisDOT)

In the WisDOT specification 2021, the requirements for concrete sidewalks are included in Sections 602 and 501. The following classes of concrete can be applicable for sidewalks: A, A2, A-FA, A-S, A-T, A-IL, A-IS, A-IP, and A-IT. Classes A and A2 are neat portland cement concrete mixtures. Classes A-FA and A-S include Class C fly ash or slag cement, respectively as partial cement replacement. Class A-IT is a ternary mixture containing portland cement, Class C fly ash, and slag. Classes A-IL, A-IS, A-IP, and A-IT refer to concrete mixtures prepared using blended portland cement types IL, IS, IP, or IT as specified in ASTM C595 [93]. In all of these concrete mixtures, the target cementitious materials factor is 565 lb/yd^3, except for Class A2 concrete, whose target cement factor is 530 lb/yd^3. For Classes A-FA, A-S, and A-T, 170 lb/yd^3 (30%) of portland cement is replaced with class C fly ash, slag, and the sum of fly ash and slag, respectively. According to Section 501.3.2.2 of the specifications, only Class C fly ash is allowed. The maximum w/cm of all sidewalk concretes is 0.47 except for Class A-FA, whose maximum w/cm=0.44. WisDOT specification requires SCM usage in all structural concrete.

Alkali silica reactivity testing and mitigation requirements are specified as follows: (1) If using coarse aggregate from sources containing significant amounts of fine-grained granitic rocks including felsic-volcanics, felsic-metavolcanics, rhyolite, diorite, gneiss, or quartzite; test coarse aggregate according to ASTM C1260 for alkali silica reactivity. Gravel aggregates are exempt from this requirement. (2) If ASTM C1260 tests indicate a 14-day expansion of 0.15 percent or greater, perform additional testing according to ASTM C1567. Test mortar bars made with coarse aggregate and the blend of cementitious materials proposed for concrete placed under the contract. The department will reject the aggregate if ASTM C1567 tests confirm mortar bar expansion of 0.15 percent or greater at 14 days [97].

The air content of concrete mixtures should be 6.0 ± 1.5%. The slump for concrete mixtures should be in a range of 1–4 inches. The temperature of concrete during the placement should be 50–80 °F. After finishing, the concrete surface must be sprayed with a uniform coating of curing compound as soon as the free water disappears. Type 2, Class A liquid curing compound conforming to ASTM C309 [98] can be used. The curing compound should be uniformly applied at a minimum rate of 1 gal per 150 ft^2. If curing compound coating is damaged within 72 hours after the application, the damaged region must be recoated. In a cold weather construction, the concrete should be protected when the air temperature is less than 40 °F within 24 hours after placement. If the air temperature is less than 40 °F, preheating of forms and reinforcement is needed. In addition, the reinforcement, base, and subgrade should be free of ice and snow.

3.3 Concrete Sidewalks - Survey Responses from PennDOT and the Six Other State DOTs

Penn State conducted a survey of PennDOT and the six other state DOTs to inquire about relevant current issues that each DOT is facing as well as their design and construction specifications for concrete sidewalks and asphalt pavements. A summary of the survey results related to concrete materials is provided below. The full survey responses are included in the Appendix.

- Important concrete-related issues that DOTs are facing:
  Fly ash supply issues (TX, MN); mid-depth horizontal delamination in continuously reinforced concrete pavements, CRCP (TX); lack of reliable and data-proven durability test methods to be used as a basis for acceptance (MI); performance of concrete repair patches (VA); workmanship issues related to dowel bar alignment – but have implemented the use of the MIT-Scan T2 to verify steel in plastic concrete (MN); joint construction concerns (PA); and surface pop-outs and scaling in sidewalks when the concrete mixture contained > 25% slag cement (PA).

- Recent changes in concrete specifications:
  Allowing portland limestone cement (type IL) in all classes of concrete (TX); allowing automated slump monitoring systems (TX); mandating the use of high-performance concrete (that includes among other requirements, 25–40% SCM) to pavements and structural concrete (MI); associating a nominal price reduction for improper curing (MI); implementing a w/cm-based specification for concrete pavements (MN); implementing the Long Life Concrete Pavements specification that includes optimized gradation among other requirements (PA); and lowering the maximum allowable slag content to 25% to reduce scaling risk (PA-District 4).

- Planned changes to concrete specifications:
  Allowing the use of natural pozzolan SCMs (TX); allowing lab-scale trial batching (TX); allowing e-ticketing (TX); testing from point of truck discharge rather than point of placement (TX); inclusion of resistivity and SAM testing (MI); updating concrete patching special provision to include more mix requirements and placement requirements (VA); green concrete mix design by reducing cement content (MN); and potential inclusion of Super Air Meter (SAM) and the Phoenix test to evaluate field w/c ratio of concrete (MN).

- Which states experience surface scaling of their concrete structures?
  Virginia: Concrete scaling issues have been observed on bridge decks, sidewalks, and pavements.
  Minnesota: Concrete scaling issues have occasionally been monitored in years. The highest occurrence of scaling is in the gutter line on bridge decks and some overall deck scaling.

- Perceived causes of scaling:
  Hand-finishing and over-finishing of the surface of concrete; SCM-rich mixtures; poor curing; inadequate application of curing compound.

- How do states mitigate surface scaling?
  Mandating proper curing method and duration; limiting the amount of chert, lightweight and deleterious pieces in aggregates; specifications allowing 5 years to file a claim against a contractor for workmanship defects; proper air entrainment.

- Types of deicing chemicals used:
  Chloride-based chemicals (e.g., $CaCl_2$, NaCl) are used as deicing chemicals. Deicers in the form of liquid brine can be also used.

3.4 Asphalt Pavements - Comparison of PennDOT Specifications with Those of the Six Other States

A moderate level of segregation was observed on the state roads 1016 and 2020 in Lackawanna County. The asphalt pavements were placed in late October/early November 2019 after milling 1.5 inches of the surface. It was reported previously that the likely cause of this problem is thermal segregation that may have occurred due to cold weather paving and limitations of compaction during the placement (see Chapter 1).

In Chapter 2, recommendations were provided on the items to be considered in providing revisions to future PennDOT asphalt-related specifications. These recommendations were made based on reviewing a series of respected national publications, national standards, and research articles regarding design and construction of asphalt pavements. Some of the items discussed and presented in Chapter 2 include balanced mix design and performance-based testing, assessing the tack bond strength, reducing potential thermal segregation, inclusion of higher RAP content and revising specifications to consider reclaimed binder ratio rather than RAP content, inclusion of recycling agents with asphalt mixes (e.g., high RAP, RAS, or plastics), and revisions to gyration levels (laboratory compaction) for different traffic levels.

Here, a comparison is made of pertinent PennDOT asphalt design and construction specifications with the latest specifications from six states (Michigan, Minnesota, North Carolina, Texas, Wisconsin, and Virginia). These comparisons include factors such as design ESALs, mixture type, aggregate gradation, compaction level, density, voids in the mineral aggregate (VMA), air voids, voids filled with asphalt (VFA), RAP/RAS content, performance tests, and cold weather paving. A comparison of specifications in different states was conducted using a summary table, which is provided at the end of this section.

The comparison of specifications is presented in tabular form, as shown in **Table 22** and **Table 23**. **Table 22** covers asphalt mix design factors while **Table 23** presents construction-related factors. For comparison, at the first row in each table, the design and construction-related parameters from the asphalt pavement projects of SR 1016 and SR 1020 are presented. Information in **Table 22** is evidence of significant similarity between PennDOT design specifications with those from selected states for most of the design parameters. The main items of difference among the specifications of PennDOT and the six other states pertaining to design and construction of asphalt pavements are provided below:

- Reclaimed Asphalt Pavement (RAP) or Recycled Asphalt Shingles (RAS):
  PennDOT currently specifies the amount of RAP or RAS in the asphalt mixture as a percent of the asphalt mixture. Other than Michigan, it appears that the reviewed states have requirements on reclaimed binder ratio rather than RAP, or they have both. PennDOT is seriously considering RBR and intends to include it in the next generation of specifications. RBR is defined as the ratio of the binder content of the recycled materials in the mix to the total binder content of the mix.

- Compaction level, density, and volumetric properties:
  The specifications of PennDOT and the reviewed six state DOTs have no big difference in compaction level, density requirements, and volumetric properties (e.g., VMA, air voids, and VFA) of asphalt mixtures.

- Balanced mix design (BMD):
  PennDOT and the reviewed six DOTs adopt volumetric properties-based asphalt mixture design. To ensure the physical and mechanical performance of asphalt mixtures, a consideration of the BMD method is needed. BMD enables development of optimal asphalt mix designs based on various performance tests. It is expected that VDOT will implement BMD criteria in 2023.

- Cold weather paving:
  To prevent thermal segregation, the requirements for air and mat temperature are specified by PennDOT and the six state DOTs. In TXDOT, the utilization of a thermal imaging system is adopted to evaluate the temperature of mat accurately.

Table 22. Requirements of material properties for asphalt pavements (asphalt mixtures comparable with asphalt used on SR1016 and SR2020, ESALs = 0.3 – 3 & Nominal aggregate size = 9.5 mm)

DOT Specs.	**Design million ESALs**	**Mix type**	**Nominal max. agg.**	**PG-Binder**	**Compaction level & Density requirements**			**Dust (or fines)-to-binder ratio**	**Volumetric properties**			**Recycled binder replacement percentage (RBR%) Both**		**Tensile strength ratio**	**Other performance testing methods**
					N_{ini}	**N_{des}**	**N_{max}**		**VMA at N_{des}**	**Air voids at N_{des}**	**VFA**	**Ratio RAP or RAS to mixture**	**Ratio of RBR to total binder**		
PennDOT Pub. 408/2020-2	0.3–3 (Bulletin 27)	-	9.5 mm (Bulletin 27)	-	7 90.5% (Bulletin 27)	75 96.0% (Bulletin 27)	115 98.0% (Bulletin 27)	0.6–1.2 (Bulletin 27)	15.5% (Bulletin 27)	4.0% (Bulletin 27)	65–78% (Bulletin 27)	5–15% RAP or 5% RAS, > 15% RAP or 5% RAS + > 5% RAP (413)	-	-	-
Michigan DOT 2012 (501)	0.3–1.0 1.0–3.0 (501.02)	E1 E3 (501.02)	No.5 - 9.5 mm (902.11)	-	7 7 90.5% (501.02)	76 86 96.0% (501.02)	117 134 98.0% (501.02)	0.6–1.2 (501.02)	15.0% (501.02)	-	65–78% 65–78% (501.02)	-	-	Min. 80% (501.02)	-
Minnesota DOT 2018 (2360)	1–3 (Level 3) (2360.2)	-	A-9.5 mm (3139.2)	-	-	60 - (2360.2)	-	0.6–1.2 (2360.2)	-	4.0% for wear 3.0% for non-wear (2360.2)	-	-	**Wear course for PG 58X-28, PG 52S-34, PG 49-34, PG 64S-22** RAS, RAP, RAS+RAP: Max. 30% **Non-wear course for PG 58X-28, PG 52S-34, PG 49-34, PG 64S-22** RAS, RAP: Max. 30% RAS+RAP: Max. 25% **Wear & Non-wear course** RAS, RAP, RAS+RAP: Max. 20% for PG58X-34 (2360.2)	Min. 75% (2360.2)	Disc-Shaped Compact Tension Test (ASTM D7313-13)
North Carolina DOT 2018 (610)	0.3–3 (610)	S9.5B (610)	9.5 mm	PG64-22 for S9.5B (610)	7 90.5% (610)	65 - (610)	-	0.6–1.4 (610)	15.5% (610)	3.0–5.0% (610)	65–80% (610)	-	**Fractionated RAP** Surface: Max. 20% Intermediate: Max. 25% Base: Max. 30% **Unfractionated RAP** Surface: Max. 10% Intermediate: Max. 10% Base: Max. 10% (610)	Min. 85% (610)	Asphalt Pavement Analyzer (AASHTO T 340-10, 2019) Max rutting depth of S9.5B: 9.5 mm

Table 22. Continued

DOT Specs.	Design million ESALs	Mix type	Nominal max. agg.	PG-Binder	Compaction level & Density requirements			Dust (or fines)-to-binder ratio	Volumetric properties			Recycled binder replacement percentage (RBR%) Both		Tensile strength ratio	Other performance testing methods
					N_{ini}	N_{des}	N_{max}		VMA at N_{des}	Air voids at N_{des}	VFA	Ratio RAP or RAS to mixture	Ratio of RBR to total binder		
Texas DOT 2014 (341)	-	-	Grade F 9.5 mm (341)	-	-	50 96.5% (341)	-	-	16.0% (341)	-	-	-	**Fractionated RAP** Surface: Max. 20% Intermediate: Max. 30% Base: Max. 40% **Unfractionated RAP** Surface: Max. 10% Intermediate: Max. 10% Base: Max. 10%	Indirect tensile strength: 85–200 psi (341)	Hamburg Wheel-Tracking Test (AASHTO T 324-19), Overlay Test (Tex-248-F) Indirect Tensile Asphalt Cracking Test (ASTM D8225-19, Tex-226-F)
Virginia DOT 2020 (211)	0–3 0–3 (211.03)	SM-9.0A SM-9.5A (211.03)	9.5 mm 9.5 mm (211.03)	Min.PG64 S-16 (PG 64-16) (211.03)	-	50 - (211.03)		0.6–1.3 0.7–1.3 (211.03)	17.0% 16.0% (211.03)	2.0–5.0% (211.03)	75–80% (211.03)	-	**Recommended PG-Binder** %RAP ≤ 25% & 25% ≤ %RBR ≤ 30% PG 64S-22 (315.04)	Min. 80% (211.02)	Asphalt Pavement Analyzer (AASHTO T 340-10, 2019), Indirect Tensile Asphalt Cracking Test (ASTM D8225-19), Cantabro Test (AASHTO TP 108-14, 2020)
Wisconsin DOT 2021 (460)	1–8 (Medium traffic)	-	9.5 mm (460.2)	-	7 89.0% (460.2)	75 96.0% (460.2)	115 98.0% (460.2)	0.6–1.2 (460.2)	15.5% (460.2)	4% (460.2)	65–75% (460.2)	-	**Intermediate & base mixes** RAS: Max. 23% RAP+RAS: Max. 45% RAP: Max. 45% **Surface mixes** RAS: Max. 20% RAP+RAS: Max. 40% RAP: Max. 40% **Recommended PG-Binder** %RBR ≤ 20% & 21% ≤ %RBR ≤ 30% PG 64-22 (460.2.5)	w/o anti-strip Min. 75% w/ anti-strip Min. 80% (460.2)	-

Table 23. Requirements of asphalt pavement placement (asphalt mixtures comparable with asphalt used on SR1016 and SR2020, ESALs = 0.3 – 3 & Nominal aggregate size = 9.5 mm)

DOT Specs.	Tack coat	Placement temperature (min. air & surface temp.)	Extension of construction period
PennDOT Pub. 408/2020-2	Tack coat and NTT/CNTT specified in Bulletin 25 Application rate: 0.03–0.05 gal/yd^2 for new asphalt 0.04–0.07 gal/yd^2 for existing asphalt 0.04–0.08 gal/yd^2 for milled surface Air temp: > 40F (460)	Air or surface temperature: > 40F Apr. 1–Oct. 15 for wearing courses Apr. 1–Oct. 31 for other courses (413)	Apr. 1–Nov. 15 for wearing course Mar.1–Dec. 15 for other courses (413)
Michigan DOT 2012 (501)	SS-1h and CSS-1h	Mat temp: > 35–50 June 1–Oct. 15 May 15–Nov. 1 May 5–Nov. 15 (501.03)	-
Minnesota DOT 2018 (2360)	CSS-1, CSS-1h Application rate of undiluted emulsion: 0.04–0.06 gal/yd^2 for new asphalt 0.05–0.09 gal/yd^2 for old asphalt 0.06–0.09 gal/yd^2 for milled asphalt Application temp: 70–160F (2357)	Until Oct. 15 Until Nov. 1 (2360.3)	-
North Carolina DOT 2018 (610)	CRS-1, CRS-1H, CRS-2, HFMS-1, RS-1H Application temp: 130–160F Air temp: > 35F Application rate: 0.04 gal/yd^2 for new asphalt 0.06 gal/yd^2 for oxidized or milled asphalt (605)	Mar. 17–Dec. 14 (> 1" thick) Apr. 1–Nov. 14 (< 1" thick) Air and mat temp: > 40F for S9.5B (610-4)	-
Texas DOT 2014 (341)	CSS-1H, SS-1H Air temp: > 60F Application rate: 0.04–0.10 gal/yd^2 (292, 341)	**w/ thermal imaging system** Mat temp.: > 32F **w/o thermal imaging system** Mat temp in daylight: > 50F for PG64 > 60F for PG70 or higher (341.4.7)	-
Virginia DOT 2020 (211)	**Tack coat** CQS-1h, CRS-1h, CSS-1h, and approved list 50.1 Application rate: 0.05–0.10 gal/yd^2 **Non-tracking tack coat** Approved list 50.1A Application rate: 0.05–0.10 gal/yd^2 (310)	**HMA** Base temp: > 80F 40F < Base temp < 80F: need to determine minimum laydown temp of asphalt **WMA** Base temperature: > 40F Mixture temperature: > 200F (315)	-
Wisconsin DOT 2021 (460)	SS-1h, CSS-1h, QS-1h, CQS-1h, or modified emulsified asphalt Air temp: > 32F Application rate: 0.05–0.07 gal/yd^2 (455.2.5)	Air temp: > 36F for upper layers, 32F for lower layers May 1–Oct. 15 Apr. 15–Nov. 1 (450.3.2.1)	-

Michigan DOT (MDOT)

In the MDOT 2012 specification, the requirements for hot-mix asphalt pavement are specified in Section 501. Depending on aggregate blend gradation criteria specified in Section 902.11, the mixture number of aggregates can be determined as provided in **Table 24**. Larger numbers refer to finer mixes used for the surface paving, while the smaller numbers cover the coarser mixes used in the binder and base layers. Mixture number 5 is a Superpave 9.5-mm mix and mixture number 4 is a Superpave 12.5-mm mix. The criteria presented in **Table 24** are different from what PennDOT uses for the designated aggregate sizes.

Table 24. Superpave final aggregate blend gradation requirements (902.11 Table 902-5)

Standard sieve	Mixture number (percent passing)				
	5	4	3	2	LVSP
1 1/2 in	-	-	-	100	-
1 in	-	-	100	90–100	-
3/4 in	-	100	90–100	≤ 90	100
1/2 in	100	90–100	≤ 90	-	75–95
3/8 in	90–100	≤ 90	-	-	60–90
No.4	≤ 90	-	-	-	45–80
No. 8	32–67	28–58	23–49	19–45	30–65
No. 16	-	-	-	-	20–50
No. 30	-	-	-	-	15–40
No. 50	-	-	-	-	10–25
No. 100	-	-	-	-	5–15
No. 200	2.0–10.0	2.0–10.0	2.0–8.0	1.0–7.0	3–6

The Superpave mix design criteria for different mixture numbers and traffic levels is provided in **Table 25**. The requirements of RAP/RAS in asphalt are not specified in the MDOT specification. However, according to the survey from the MDOT, the maximum amount of RAS binder should be less than 17% by weight of the total binder content for any hot-mix asphalt mixture. In case of RAP, there is no limit, but it should meet the volumetric parameters, which act as limiting factors. The maximum amount of RAP/RAS binder for high traffic volume mixes is limited to 27% by weight of total binder content. As a bond coat, anionic emulsified asphalt (SS-1h) and cationic emulsified asphalt (CSS-1h) are applied.

The weather and seasonal limitations are provided in Section 501.03. The placement of hot-mix asphalt is not allowed if the temperature of surface being paved is lower than 35 °F. The minimum surface temperature dictates the minimum density of asphalt that can be placed. If temperature of the surface is greater than 35 °F, the minimum amount of HMA allowed to be placed is 200 lb/yd^2. If the temperature of the surface is at least 40 °F, then no less than 120 lb/yd^2 can be placed. For surface temperatures exceeding 50 °F, any amount of HMA is allowed. To put these numbers in perspective, 200 lb/yd^2 translates roughly into 1 and 3/4 inches of asphalt pavement thickness, and 120 lb/yd^2 results in slightly over 1-inch thickness. For comparison, PennDOT requires a minimum surface temperature of 40 °F for asphalt mixtures and increases the minimum surface temperature to 50 °F when 1-inch-thick layers or stone mastic asphalt is used. The seasonal limitations for asphalt paving deliver a shorter construction season compared with PennDOT specifications. Depending on the climatic region in the state, it is either from June 1 to October 15, May 15 to November 1, or May 5 to November 15.

With six different traffic levels (ESALs) to decide the number of gyrations for mix design, Michigan stands in a unique situation compared with many states including Pennsylvania. The reason for so many different gyration levels is not clear, but the overall trend for more states including PA within the last decade has been decreasing the number of gyrations for design.

Table 25. Superpave mix design criteria (provided in 501.02 Table 501-1, 2, and 3)

Design parameter	Mix number of aggregate				
	5	**4**	**3**	**2**	**LVSP**
% of G_{mm}* at N_{des}**	96.0%				
% of G_{mm} at N_{ini}***	See below VFA and compaction criteria				
% G_{mm} at N_{max}****	98%				
VMA minimum % at N_{des}	15%	14%	13%	12%	14%
VFA at N_{des}	See below VFA and compaction criteria				
Fines to effective asphalt binder ratio	0.6 – 1.2%				
Tensile strength ratio	Min. 80%				
Application rates (lb/yd^2)	Top 165–220	Leveling, Top 220–275	Base, leveling 330–410	Base 435–550	Leveling, Top 165–250 Base 220–330

VFA minimum and maximum criteria & Superpave gyratory compactor compaction criteria

Million ESALs***	Mix type	VFA for tope & leveling courses	VFA for base course	% G_{mm}* at N_{ini}	Number of gyrations**		
					N_{ini}	N_{des}	N_{max}
≤ 0.3	LVSP	70–80	70–80	91.5%	6	45	70
≤ 0.3	E03	70–80	70–80	91.5%	7	50	75
> 0.3 – ≤ 1.0	E1	65–78	65–78	90.5%	7	76	117
> 1.0 – ≤ 3.0	E3	65–78	65–78	90.5%	7	86	134
> 3.0 – ≤ 10	E10	65–78	65–75	89.0%	8	96	152
> 10 – ≤ 30	E30	65–78	65–75	89.0%	8	109	174
> 30 – ≤ 100	E50	65–78	65–75	89.0%	9	126	204

*G_{mm}: maximum specific gravity
**Notes: N_{des}: design number of gyrations
**Notes: N_{ini}: initial number of gyrations
**Notes: N_{max}: maximum number of gyrations
***ESAL: equivalent single-axle loads

Minnesota DOT (MNDOT)

In the MNDOT 2018 specification, the requirements of asphalt pavement are specified in Section 2360. The requirements of aggregate gradation and mix design criteria are decided based on traffic level (design ESALs) as provided in **Table 26** and **Table 27**, respectively. The aggregate gradation for bituminous mixtures is provided in Section 3139. The aggregate gradation should meet the requirements in accordance with AASHTO T 11 and AASHTO T 27 [101,102]. The minimum percent of added new asphalt binder to total asphalt binder ratio is provided in **Table 28**. The bituminous materials for tack coat are medium cure cutback asphalt (MC-250) at the early and late construction season (< 32 °F) and emulsified asphalt of CSS-1 and CSS-1h. Emulsion of CSS-1 or CSS-1h can be used as a form of undiluted and diluted conditions (70% emulsion and 30% water) having minimum residual asphalt content of 57% and 40%, respectively. The application rate of tack coat is provided in **Table 29**. Comparing this specification with PennDOT Spec 160 indicates that the application rates are comparable considering the fact that PennDOT application rates are based on the asphalt residue and MN application rates are based on diluted or undiluted emulsions. The application temperatures of CSS-1 and CSS-1h, and MC-250 are 70–160 °F and 165–220 °F, respectively. WMA is allowed on all projects. Any mix that is produced at temperatures 30 °F or lower than typical HMA mixing temperature of the asphalt binder, as defined by the asphalt supplier, is considered as WMA. The WMA can be manufactured through use of foamed asphalt and/or chemical additive processes. Placing the wearing course of asphalt pavement is not allowed after October 15 or after November 1 depending on the state's climatic region.

Table 26. Aggregate gradation (Section 3139.2 Table 3139-2)

Standard sieve	**Percent passing of total washed gradation**			
	A	**B**	**C**	**D**
1 in	-	-	100	-
3/4 in	-	100	85–100	-
1/2 in	100	85–100	45–90	-
3/8 in	85–100	35–90	-	100
No.4	60–90	30–80	30–75	65–95
No. 8	60–90	25–65	25–60	45–80
No. 200	2.0–7.0	2.0–7.0	2.0–7.0	3.0–8.0

Table 27. Mixture design criteria (Section 2360.2 Table 2360-7)

Traffic level	2	3	4	5
20 year design ESALs	< 1 million	1 – 3 million	3 – 10 million	10 – 30 million
Gyratory mixture requirements:				
N_{des}	40	60	90	100
Air voids at N_{des}, wear	4.0%			
Air voids at N_{des}, non-wear and all shoulder	3.0%			
Adjusted asphalt film thickness	8.5 μm			
Minimum tensile strength ratio	75%	75%	80%	80%
Ratio of fines to effective asphalt	0.6–1.2			

Table 28. Requirements for ratio of added new asphalt binder to total asphalt binder ratio (Section 2360.2 Table 2360-8)

Asphalt grade	Recycled material		
	RAS only	RAS + RAP	RAP only
PG 58X*-28, PG 52S-34, PG 49-34, PG 64S-22			
Wear courses	70%	70%	70%
Non-wear courses	70%	70%	65%
PG58X*-34			
Wear & non-wear courses	80%	80%	80%

*X: S, H, V, E

Table 29. Application rate of tack coat (Section 2357.5 Table 2357-2)

Surface type	Application rate (gal/yd^2)		
	Undiluted emulsion	Diluted emulsion (70% emulsion, 30% water)	MC cutback
New asphalt	0.04–0.06	0.06–0.09	0.05–0.07
Old asphalt	0.05–0.09	0.075–0.135	0.09–0.11
Milled asphalt	0.06–0.09	0.09–0.135	0.09–0.11

North Carolina DOT (NCDOT)

In the NCDOT Specification 2018, the requirements for asphalt pavements are specified in Section 610. The gradation of aggregate should meet the requirements provided in **Table 30**. Mix design criteria for asphalt mixtures and replacement percentage of RAP/RAS are provided in **Table 31** and **Table 32**, respectively. In Specification Section 610-9, the minimum percentage of the maximum specific gravity of asphalt after the compaction should be 85% for S4.75A, 90% for SF9.5A, and 92% for S9.5X, I19.0X, and B25.0X. Depending on the percentage of recycled binder ratio, the minimum binder grade requirements are determined as shown in **Table 33**. The mixing temperatures of asphaltic material at the plant are 250–290 °F for PG58-28 and PG64-22, 275–305 °F for PG70-22, and 300–325 °F for PG76-22. When RAS is used, the JMF mix temperature should be established at 275 °F or higher. The information of emulsified asphalt tack coat (e.g., CRS-1, CRS-1h, CRS-2, HFMS-1, and RS-1H) are provided in Section 605. Tack coat should be applied at the atmospheric temperature of 35 °F or above. The application rates for tack coat on new asphalt and milled asphalt are 0.04 ± 0.01 gal/yd^2 and 0.06 ± 0.01 gal/yd^2, respectively. The application temperature of tack coat should be in a range of 130–160 °F.

With the use of a hauling vehicle, temperature of the mixture should be within a tolerance of ±25 °F of the JMF mix temperature, while MTV is only required to be used for PG 76-22 and for all types of open-graded friction course (OGFC). Temperature and seasonal limitations for placing asphalt mixtures are specified in Section 610-4. The minimum surface and air temperature for the asphalt placement varies depending on the traffic level and performance grade of the binder. As traffic level increases or the binder becomes stiffer (higher PG), the minimum required temperature increases. The range is 35 °F to 50 °F, with the former applicable to 25-mm base course and the latter for the highest trafficked roads using PG 76-22. For other mixes, the minimum temperature is either 40 °F or 45 °F depending on the mix. For the final layer of surface mixes containing RAS, the minimum surface and air temperature should be 50 °F. The placement of surface course material (final layer) is not allowed between December 15 and March 16 of the next year if it is 1 inch or greater in thickness or between November 15 and April 1 of the next year if it is less than 1 inch in thickness. As an exception, once the placement of a layer of asphalt base course material or intermediate material (2 inches or greater thickness) has started, it can continue until the temperature drops to 32 °F.

Table 30. Aggregate gradation criteria (Section 610-3 Table 610-2)

Standard sieve	**Percent passing of aggregate (Nominal aggregate size)**			
	4. 75 mm	**9.5 mm**	**19.0 mm**	**25. 0 mm**
1 1/2 in (37.5 mm)	-	-	-	100
1 in (25.0 mm)	-	-	100	90–100
3/4 in (19.0 mm)	-	-	90–100	<90
1/2 in (12.5 mm)	100	100	< 90	-
3/8 in (9.5 mm)	95–100	90–100		-
No.4 (4.75 mm)	90–100	< 90		-
No. 8 (2.36 mm)	-	32–67	23–49	19–45
No. 16 (1.18 mm)	30–60	-	-	-
No. 200 (0.075 mm)	6–12	4–8	3–8	3–7

Table 31. Mix design criteria for asphalt mixtures (Section 610-3 Table 610-3)

Mix type**	20-year design million ESALs	Binder PG grade	Compaction levels		Max rutting depth (mm)	Volumetric properties			
			N_{ini}	N_{des}		VMA (%min)	VTM*	VFA	%G_{mm} at N_{ini}
S4.75A	< 1	PG64-22	6	50	11.5	16.0%	4–6%	65–80%	≤ 91.5%
SF9.5A	< 0.3	PG64-22	6	50	11.5	16.0%	3–5%	70–80%	≤ 91.5%
S9.5B	0.3–3	PG64-22	7	65	9.5	15.5%	3–5%	65–80%	≤ 90.5%
S9.5C	3–30	PG70-22	7	75	6.5	15.5%	3–5%	65–78%	≤ 90.5%
S9.5D	> 30	PG76-22	8	100	4.5	15.5%	3–5%	65–78%	≤ 90.0%
I19.0B	< 3	PG64-22	7	65	-	13.5%	3–5%	65–78%	≤ 90.5%
I19.0C	3–30	PG64-22	7	75	-	13.5%	3–5%	65–78%	≤ 90.0%
I19.0D	> 30	PG70-22	8	100	-	13.5%	3–5%	65–78%	≤ 90.0%
B25.0B	< 3	PG64-22	7	65	-	12.5%	3–5%	65–78%	≤ 90.5%
B25.0C	> 3	PG64-22	7	75	-	12.5%	3–5%	65–78%	≤ 90.0%
	Design parameter				**Design criteria**				
All mix types	**Dust to binder ratio**				0.6–1.4				
	Tensile strength ratio				Min. 85%				

*VTM: Voids in total mix (compatible with air voids)

**Notes:

Suffix: "A" for ESALs < 1.0, "B" for ESALs < 3.0, "C" ESALs 3–30, "D" for ESALs > 30.

Number: 4.75, 9.5, 19.0, 25.0 means nominal maximum aggregate size.

Prefix of "S" and "SF" for surface layer, "I" for intermediate layer, and "B" for base layer.

Table 32. Maximum percent of recycled binder replacement per total asphalt binder content (Section 610-3 Table 610-4)

Recycled materials	Intermediate & base mixes	Surface mixes	Mixes using PG76-22
RAS	23%	20%	18%
RAP or RAP/RAS combination	45%	40%	18%

Table 33. Binder grade requirements (Section 610-3 Table 610-5)

Mix type	%RBR ≤ 20%	21% ≤ %RBR ≤ 30%	%RBR >30%
S4.75A, SF9.5A, S9.5B, I19.0B, I19.0C, B25.0B, B25.0C	PG64-22	PG64-22	PG58-28
S9.5C, I19.0D	PG70-22	PG64-22	PG58-28
S9.5D, Open graded friction course (OGFC)	PG76-22	n/a	n/a

Texas DOT (TXDOT)

In the TXDOT Specification 2014, the requirements for dense-graded hot-mix asphalt are specified in Section 341. The specifications for aggregate gradation and VMA are provided in **Table 34**. Mix design criteria for asphalt are summarized in **Table 35**. Design number of gyrations for compaction is 50 with the requirements of 96% density. The number of gyrations can be reduced to no less than 35 gyrations at the contractor's discretion. The maximum ratio of recycled asphalt binder (e.g., RAP and RAS) to total binder content is provided in **Table 36**. Tack coat of CSS-1H and SS-1H can be placed only when the roadway surface temperature is 60 °F or higher. The application rate of tack coat should be between 0.04–0.10 gal/yd^2 as specified in 292.

Placement of asphalt mixtures is allowed if the roadway surface temperature is at least 32 °F, determined by thermal imaging system. When thermal imaging system is not used, the minimum surface temperature is 45 °F (night paving) and 50 °F (daylight operation) for PG 64 or lower grades, 55 °F (night paving) and 60 °F (daylight operation) for PG 70, and 60 °F for PG 76 or higher grades. The asphalt mixtures should be hauled using belly dumps, live bottom, or end dump trucks. End dump trucks are only allowed when used in conjunction with an MTV with remixing capability or when thermal imaging system is used. After compaction of the pavement, the in-place air voids should be between 3.8% and 8.5%.

Table 34. Requirements of aggregate gradation and VMA (Section 341 Table 8)

Standard sieve	**Percent passing of aggregate**				
	A Coarse base	**B Fine base**	**C Coarse surface**	**D Fine surface**	**F Fine mixture**
2 in (75.0 mm)	100	-	-	-	-
1 1/2 in (37.5 mm)	98–100	100	-	-	-
1 in (25.0 mm)	78–94	98–100	100	-	-
3/4 in (19.0 mm)	64–85	84–98	95–100	100	-
1/2 in (12.5 mm)	50–70	-	-	98–100	100–
3/8 in (9.5 mm)	-	60–80	70–85	85–100	98–100
No.4 (4.75 mm)	30–50	40–60	43–63	50–70	70–90
No. 8 (2.36 mm)	22–36	29–43	32–44	35–46	38–48
No. 30 (0.60 mm)	8–23	13–28	14–28	15–29	12–27
No. 50 (0.30 mm)	3–19	6–20	7–21	7–20	6–19
No. 200 (0.075 mm)	2–7	2–7	2–7	2–7	2–7
Design VMA					
-	Min. 12.0%	Min. 13.0%	Min. 14.0%	Min. 15.0%	Min. 16.0%
Production (plant-produced) VMA					
-	Min. 11.5%	Min. 12.5%	Min. 13.5%	Min. 14.5%	Min. 15.5%

Table 35. Mix design criteria for asphalt (Section 341 Table 9 and 10)

Mix design criteria		**Requirement**
Target laboratory-molded density (G_{mm})		96.5%
Number of gyration (N_{des})		50
Indirect tensile strength		85–200 psi
Hamburg wheel test (Min. number of passes at 12.5 mm rutting depth at 50C)	**PG64 or lower**	10000
	PG70	15000
	PG76 or higher	20000

Table 36. Maximum allowable ratio of recycled binder to total asphalt binder (Section 341 Table 4 and 5)

Maximum allowable amount of RAP					
Fractionated RAP			**Unfractionated RAP**		
Surface	**Intermediate**	**Base**	**Surface**	**Intermediate**	**Base**
20%	30%	40%	10%	10%	10%
Maximum ratio of recycled binder to total binder					
originally specified PG binder		**Allowable substitute PG binder**	**Surface**	**Intermediate**	**Base**
HMA	**76-22**	70-22, 64-22	20%	20%	20%
		70-28, 64-28	30%	35%	40%
	70-22	64-22	20%	20%	20%
		64-28, 58-28	30%	35%	40%
	64-22	58-28	30%	35%	20%
	76-28	70-28, 64-28	20%	20%	40%
		64-34	30%	35%	20%
	70-28	64-28, 58-28	20%	20%	40%
		64-34, 58-34	30%	35%	20%
	64-28	58-28	20%	20%	40%
		58-34	30%	35%	20%
WMA*	**76-22**	70-22, 64-22	30%	35%	40%
	70-22	64-22, 58-28	30%	35%	40%
	64-22	58-28	30%	35%	40%
	76-28	70-28, 64-28	30%	35%	40%
	70-28	64-28, 58-28	30%	35%	40%
	64-28	58-28	30%	35%	40%

*WMA: Temperature of WMA is 215-275 °F using approved WMA additives

Virginia DOT (VDOT)

In the VDOT specification 2020, the requirements for asphalt mixtures are specified in Section 211. The aggregate gradation for asphalt concrete is provided in **Table 37**. Type of mixes at given ESALs and mix design criteria are provided in **Table 38** and **Table 39**, respectively. Asphalt concrete should be selected at 4.0% air voids for A and D mixes, 3.5% air voids for the E mix. Base mix shall be designed at 2.5% air voids. BM-25A shall have a minimum asphalt content of 4.4% unless otherwise approved by the Engineer. BM-25D shall have a minimum asphalt content of 4.6% unless otherwise approved by the Engineer. The recommended performance grade asphalt binder is varied depending on the ratio of RAP binder to total asphalt binder in the mix (see **Table 40**). The amount of RAS used in the mixture should be no more than 5% of the total mixture weight. However, the combined percentages of RAS and RAP binder content should be less than 30% of mass of total asphalt content of mixtures according to the following equation.

$$\frac{\%RAS_{mix} \times \frac{\%AC_{RAS}}{100} + \%RAP_{mix} \times \frac{\%AC_{RAP}}{100}}{\%AC_{JMF}} \leq 30.0\%$$

where $\%RAS_{mix}$ is percent RAS in the JMF, $\%AC_{RAS}$ is average percent asphalt content in the RAS, $\%RAP_{mix}$ is percent RAP in the JMF, $\%AC_{RAP}$ is average percent asphalt content in the

RAP, and $\%AC_{JMF}$ is design asphalt content of the JMF. Asphalt tack coat should be CQS-1h, CRS-1h, or CSS-1h conforming to Section 210 of the Specifications and selected from the Department's approved list 50.1. Asphalt emulsion CMS-2 can be used during the winter months. Non-tracking tack coat should be selected from the Department's approved list 50.1 and conforming to Section 210. The application rate of tack coat and non-tracking tack coat is 0.05–0.10 gal/yd^2 as specified in 310.03.

The minimum base and laydown temperatures for surface mixes are varied depending on the temperatures of the base and asphalt mixes. If WMA is used, the base and mixture temperatures should be higher than 40 °F and 200 °F, respectively. In case of HMA, if the base temperature is higher than 80 °F, laydown of the mixture is allowable at any temperature conforming to the requirements. If base temperature is between 40 °F and 80 °F, the minimum laydown temperature of asphalt should follow the requirements specified in **Table 41**. When the laydown temperature of HMA is between 301 °F and 325 °F, the number of compaction rollers should be the same number as those required for 300 °F condition.

Table 37. Requirements of aggregate gradation for asphalt concrete (Section 221.03 Table II-13)

Standard sieve	Percentage by weight passing					
	SM-9.0 A, D, E	SM-9.5 A, D, E	SM-12.5 A, D, E	IM-19.0 A, D, E	BM-25.0 A, D	C (curb mix)
2 in (75.0 mm)	-	-	-	-	-	-
1 1/2 in (37.5 mm)	-	-	-	-	100	-
1 in (25.0 mm)	-	-	-	100	90–100	-
3/4 in (19.0 mm)	-	-	100	90–100	Max. 90	-
1/2 in (12.5 mm)	100	100	95–100	Max. 90	-	100
3/8 in (9.5 mm)	90–100	90–100	Max. 90	-	-	92–100
No.4 (4.75 mm)	Max. 90	58–80	58–80	-	-	70–75
No. 8 (2.36 mm)	47–67	38–67	34–50	28–49	19–38	50–60
No. 30 (0.60 mm)	-	Max. 23	Max. 23	-	-	28–36
No. 50 (0.30 mm)	-	-	-	-	-	15–20
No. 200 (0.075 mm)	2–10	2–10	2–10	2–8	1–7	7–9

Table 38. Type of mix at given ESALs range (Section 211)

Mix type	Millions ESALs	Minimum asphalt PG grade	Aggregate nominal maximum size
SM-9.0A	0–3	64S-16	3/8 in
SM-9.0D	3–10	64H-16	3/8 in
SM-9.0E	> 10	64E-22	3/8 in
SM-9.5A	0–3	64S-16	3/8 in
SM-9.5D	3–10	64H-16	3/8 in
SM-9.5E	> 10	64E-22	3/8 in
SM-12.5A	0–3	64S-16	1/2 in
SM-12.5D	3–10	64H-16	1/2 in
SM-12.5E	> 10	64E-22	1/2 in
IM-19.0A	< 10	64S-16	3/4 in
IM-19.0D	10–20	64H-16	3/4 in
IM-19.0E	> 20	64E-22	3/4 in
BM-25.0A	All ranges	64S-16	1 in
BM-25.0D	> 10	64H-16	1 in

*Note: SM = surface mixture, IM = intermediate mixture, BM = base mixture
**Number: 9.0, 12.5, 19.0, and 25.0 means nominal maximum aggregate size
***Prefix: “A” = million ESAL 0–3, “D” = million ESAL 3 – 10, “E” = million ESAL > 10

Table 39. Mix design criteria for asphalt concrete (Section 211.03 Table II-14)

Mix type	VTM* production	VFA design	VFA production	Min VMA	Fines/asphalt ratio	No. of gyration (N_{des})
SM-9.0A	2.0-5.0	75-80	70-85	17	0.6-1.3	50
SM-9.0D	2.0-5.0	75-80	70-85	17	0.6-1.3	50
SM-9.0E	2.0-5.0	75-80	70-85	17	0.6-1.3	50
SM-9.5A	2.0-5.0	75-80	70-85	16	0.7-1.3	50
SM-9.5D	2.0-5.0	75-80	70-85	16	0.7-1.3	50
SM-9.5E	2.0-5.0	75-80	70-85	16	0.7-1.3	50
SM-12.5A	2.0-5.0	73-79	68-84	15	0.7-1.3	50
SM-12.5D	2.0-5.0	73-79	68-84	15	0.7-1.3	50
SM-12.5E	2.0-5.0	73-79	68-84	15	0.7-1.3	50
IM-19.0A	2.0-5.0	69-76	64-83	14	0.6-1.3	50
IM-19.0D	2.0-5.0	69-76	64-83	14	0.6-1.3	50
IM-19.0E	2.0-5.0	69-76	64-83	14	0.6-1.3	50
BM-25.0A	1.0-4.0	67-87	67-92	13	0.6-1.3	50
BM-25.0D	1.0-4.0	67-87	67-92	13	0.6-1.3	50

*In the VDOT specification, it is VFA, but it would be a typo. Penn State believes that it would be VTM based on a review of Section 211.03.

Table 40. Recommended performance grade of asphalt cement (Section 211.03 Table II-14A)

Mix type	Percentage of reclaimed asphalt pavement (RAP) to total binder in mix		
	%RAP ≤ 25.0%	25.0% < %RAP ≤ 30.0%	25.0% < %RAP ≤ 35.0%
SM-4.75A, SM-9.0A, SM-9.5A, SM-12.5A	PG64S-22	PG64S-22	-
SM-4.75D, SM-9.0D, SM-9.5D, SM-12.5D	PG64H-22	PG64S-22	-
IM-19.0A	PG64S-22	PG64S-22	-
IM-19.0D	PG64H-22	PG64S-22	-
BM-25.0A	PG64S-22	-	PG64S-22
BM-25.0D	PG64H-22	-	PG64S-22

Table 41. Temperature limitations for the placement of asphalt: minimum base and laydown temperature for surface mixes (Section 315.04)

PG binder/mix designation	Percentage of RAP added to mix	Minimum base temperature	Minimum placement temperature
PG64S-22 (A)	≤ 25%	40 °F	250 °F
PG64S-22 (A)	> 25%	50 °F	270 °F
PG64H-22 (D)	≤ 30%	50 °F	270 °F
PG64E-22 (E)	≤ 15%	50 °F	290 °F
PG64S-22 (S)	≤ 30%	50 °F	290 °F

Wisconsin DOT (WisDOT)

In the WisDOT specification 2021, the requirements for asphalt pavement are specified in Section 460. The requirements of aggregate gradation and VMA are provided in **Table 42**. The design criteria for asphalt mixtures depending on traffic load are provided in **Table 43**. The ratio of recycled asphaltic binder (e.g., binder from RAS, RAP, and FRAP—Fractionated RAP) to total binder is provided in **Table 44**. The types of tack coat specified in 455.2.5 for asphalt pavements are SS-1h, CSS-1h, QS-1h, CQS-1h, or modified emulsified asphalt with an "h" suffix. Tack coat should be applied when the air temperature is higher than 32 °F. The application rate of tack coat is between 0.05 gal/yd^2 and 0.07 gal/yd^2 after dilution. Dilutions of anionic emulsified asphalts, cationic emulsified asphalts, and polymer-modified cationic emulsified asphalts need to conform to AASHTO M 140, M 208, and M 316, respectively. Residues are 57% for SS-1h and CSS-1h and 62% for CQS-1h.

In the construction of asphalt pavements in cold weather, the air temperature should be higher than 40 °F for the placement of asphalt mixtures. The asphalt should be delivered at a temperature within 20 °F of the temperature the asphalt supplier recommends. When the ambient air temperature is less than 65 °F, covers are needed to minimize heat loss during the delivery. PennDOT specification requires tarping and covering at all times regardless of temperature, and in fact the practice exercised by PennDOT is preferred to the practice of using covering depending on the temperature.

Table 42. Requirements of aggregate gradation (Section 460.2 Table 460-1)

Standard sieve	**Percent passing & Nominal size**							
	No. 1 (37.5 mm)	**No. 2 (25.0 mm)**	**No. 3 (19.0 mm)**	**No. 4 (12. 5 mm)**	**No. 5 (9.5 mm)**	**No. 6 (4.75 mm)**	**SMA No. 4 (12. 5 mm)**	**SMA No. 5 (9.5 mm)**
2 in (50.0 mm)	100	-	-	-	-	-	-	-
1 1/2 in (37.5 mm)	90–100	100	-	-	-	-	-	-
1 in (25.0 mm)	Max. 90	90–100	100	-	-	-	-	-
3/4 in (19.0 mm)	-	Max. 90	90–100	100	-	-	100	-
1/2 in (12.5 mm)	-	-	Max. 90	90–100	100	-	90–97	100
3/8 in (9.5 mm)	-	-	-	Max. 90	90–100	-	58–80	90–100
No.4 (4.75 mm)	-	-	-	-	Max. 90	100	25–35	35–45
No. 8 (2.36 mm)	15–41	19–45	23–49	28–58	32–67	90–100	15–25	18–28
No. 16 (1.18 mm)	-	-	-	-	-	Max. 90	-	-
No. 30 (0.60 mm)	-	-	-	-	-	30–55	Max. 18	Max. 18
No. 200 (0.075 mm)	0–6.0	1.0–7.0	2.0–8.0	2.0–10.0	2.0–10.0	-	8.0–11.0	8.0–12.0
% VMA	Min. 11.0%	Min. 12.0	Min. 13.0	Min. 14.0	Min. 15.0	6.0–13.0	Min. 16.0	Min. 17.0

Table 43. Requirements of asphalt mixtures (Section 460.2.7 Table 460-2)

Design parameter		**LT mix**	**MT mix**	**HT mix**	**SMA (stone matrix asphalt)**
Design million ESALs		≤ 1	> 1 – ≤ 8	> 8	> 2
Number of gyrations for compaction	N_{ini}	6	7	8	7
	N_{des}	40	75	100	65
	N_{max}	60	115	160	100
Air voids		4.0	4.0	4.0	4.5
% G_{mm} at N_{des}		96.0%	96.0%	96.0%	95.5%
% G_{mm} at N_{ini}		≤ 91.5%	≤ 89.0%	≤ 89.0%	-
% G_{mm} at N_{max}		≤ 98.0%	≤ 98.0%	≤ 98.0%	≤ 98.0%
Dust to binder ratio		0.6–1.2			1.2–2.0
% VFA		68–80%	65–75%	65–75%	70–80%
Tensile strength ratio	without anti stripping additive	Min. 75%	Min. 75%	Min. 75%	Min. 80%
	With antistripping additive	Min. 80%	Min. 80%	Min. 80%	Min. 80%
Minimum effective asphalt content		-	-	-	5.5%

Table 44. Maximum allowable percent binder replacement (Section 460.2.5)

Recycled asphaltic material	**Lower layers**	**Upper layer**
RAS only	25%	20%
RAP and FRAP in combination	40%	25%
RAS, RAP, and FRAP in combination	35%	25%

3.5 Asphalt Pavements - Survey Response from PennDOT and the Six Other State DOTs

Details of information gathered from the surveyed states can be found in the Appendix. However, the following synopsis shows how these states deal with several specific issues that have been particularly of great interest to investigate as related to this research project. These items include cold weather paving, seasonal limitations, mix design issues, and use of recycled materials.

- Cold weather paving:
  Almost all surveyed states consider cold weather paving a challenge and discuss the potential for segregation, low density, and long-term problems. Some discuss having observed cold weather paving issues, most notably low density and segregation, but also pickup of the mix by pneumatic rubber tire roller when polymer-modified binder is used. The measures taken to remedy the problem include tarping of the mix, insulated trucks, use of WMA, paving thicker layers, increased plant temperature, and use of thermal imaging.

The survey response received from PennDOT District 4 indicates that the district has faced the problem of thermal segregation in the past. The response from the PennDOT central office is also indicative of concerns with cold weather paving, as it is mentioned in their feedback that loss of fines at the surface of asphalt pavement is experienced during cold weather in a first year after the paving. To mitigate the issues related to segregation and low density of asphalt pavement, PennDOT District 4 follows specifications that require placement of the material only when air temperature is higher than 40 °F. In addition, contractors need to submit documents of "Extended-Season Paving Plan" and "Extended-Season Paving Quality Control Documentation." However, PennDOT does not require monitoring of the mat temperature during cold weather paving.

Texas and Minnesota appear to be the only states among those surveyed requiring or encouraging the use of paver-mounted thermal imaging equipment. Texas has a test procedure for thermal imaging (Tex-244: Thermal Profile of Hot Mix Asphalt), which requires use of either a paver-mounted thermal imaging system or a hand-held thermal imaging camera used immediately behind the paver. It may be a good approach for PennDOT to encourage the use of thermal profiling in cold weather paving, maybe through incentivizing the usage. PennDOT may also require higher minimum mix temperature when paving in cold temperature. Other measures such as insulated trucks and tarping are already in place in PennDOT specifications. According to the survey from PennDOT, PennDOT strives to maintain temperature of asphalt mixtures higher than 40 °F during the shipping and placement.

- Seasonal limitations and minimum surface temperature:
  An important focus of our attention when comparing specifications of various state DOTs was the minimum pavement temperature and extended season for paving as related to the projects placed on SR 1016 and SR 2020 in late season. It was interesting to see differences in how states address this issue. Michigan specifies minimum surface temperature depending on the amount of material placed per square yard, starting at minimum of 35 °F for thicker layers and increasing this minimum to 50 °F as the pavement becomes thinner. Michigan also has indicated that it plans to remove the language on seasonal limitations and solely rely on air and surface limitations.

  North Carolina's specification for minimum surface temperature depends on traffic level, binder performance grade, and the pavement layer, varying between 35 °F and 50 °F. The highest trafficked roads using PG 76-22 in the surface mix require the highest minimum pavement temperature to be 50 °F. Texas ties the minimum required temperature to how the mix temperature is measured. The minimum allowed surface temperature is 32 °F if a thermal imaging system is used; otherwise the minimum temperature varies between 45 °F and 60 °F depending on the binder grade and whether paving takes place during the day or the night.

  Virginia has a unique approach for dealing with the surface temperature. The minimum allowed surface temperature is 40 °F, but this minimum must increase to 50 °F for certain conditions, and those conditions depend on the performance grade of the binder and the amount of RAP used in the mix. The surface temperature, the binder grade, and the amount of RAP in the mix also dictate what the minimum asphalt mixture temperature shall be at the time of placement. For example, when PG 64S-22 is used with less than 25% RAP, the minimum base temperature must be 40 °F and the mix temperature at the time of placement muse be at least 250 °F. On the other hand, for the same binder but using RAP content higher than 25%, the minimum base temperature and the minimum mix temperature increase to 50 °F and 270 °F, respectively. PennDOT requires a minimum surface temperature of 40 °F when placing asphalt mixtures and increases the minimum temperature to 50 °F for stone mastic asphalt and when the compacted thickness is only one inch. These values are reasonable and comparable with the values found in the surveyed states.

- Mix design considerations and balanced mix design:
  There are differences among the surveyed states on how they specify the asphalt mix design process. For example, Michigan is considering reduction of the number of mix categories and related compaction gyration levels, and that is similar to what Pennsylvania is investigating. Minnesota is considering Superpave5, which is a modified version of the Superpave design. In Superpave5, the mix is designed at 5% air void rather than 4% but at a reduced number of gyrations, with the final outcome of a similar asphalt content, but better field compaction. Minnesota is considering reduction of gyrations levels to 30 and 50 with the Superpave5 design.

  The survey also indicates that some of the states are seriously considering use of balanced mix design and performance testing. Some states already have such tests as part of their specifications. For example, Texas uses Hamburg Wheel Tracking and indirect tensile strength for rutting and moisture damage, Texas Overlay Tester for fatigue cracking, and the Cantabro test for Open Graded Friction Courses. Texas is looking into the use of shear bond test to evaluate tack coat. North Carolina uses the Asphalt Pavement Analyzer (APA) for rutting. Other states discuss their interest in pursuing performance tests and building these tests into future specifications. For example, Virginia is considering IDEAL-CT, APA, and Cantabro as performance tests to be implemented for both design and production in 2023. Wisconsin is also looking into cracking and rutting tests. PennDOT has already started on the path of BMD and has used performance tests for several pilot projects within the last few years and intends to do so for future projects. According to the survey from PennDOT central office, the BMD approach using asphalt mixture performance tests is in progress and it is expected that full implementation will take place in 2025. To support the BMD approach, PennDOT has implemented pilot projects to collect the performance test data of asphalt mixtures using Hamburg Wheel Track test and IDEAL-CT test.

- RAP/RAS usage:
  With respect to the use of RAP/RAS, some states such as Texas and Wisconsin have already built reclaimed binder ratio into their specifications instead of using the RAP/RAS contents, and some have limits on both the RAP/RAS content and RBR. Texas and Wisconsin have a tiered approach on the use of RAP/RAS, depending on the pavement layer, with the surface having the lowest RBR and the base the largest RBR. In Texas, the surface RBR is limited to 0.20 and in Wisconsin it is limited to 0.25 for RAP/RAS combination. In case of using RAS only, the RBR is limited to 0.20 in Wisconsin.

  Minnesota also has a tiered approach on RAP content based on the binder performance grade. For example, when using PG XX-28, maximum of 30% RAP is allowed while with PG XX-34, RAP is limited to 20%. All states limit the RAS content to 5%. The researchers believe that PennDOT is on the right track implementing RBR instead of

RAP/RAS content. It is recommended that higher RBR be allowed for binder and base courses. It is also important to consider the performance grade of the RAP/RAS binder in deciding the RBR limit when high content of recycled material is used.

According to the survey from PennDOT central office, it was reported that asphalt mixtures using RAP (> 15%) and high RAP (> 25%) are more common than before in industry. PennDOT has implemented two Standard Special Provisions (SSP) for high RAP asphalt mixes for low-volume roadways (to cover wearing and binder courses) and is in the process of implementing a third SSP.

3.6 Review of Recent Research Conducted by the Six State DOTs

Penn State investigated recent research conducted by six state DOTs focusing on methods for improving the quality of asphalt pavement as well as utilization of RAP. A summary of recent research from Michigan, Minnesota, Virginia, and Wisconsin DOTs is summarized as follows:

In 2018, Michigan DOT [103] investigated best practices in pavement materials, design, methodologies, technologies of construction, and strategies of maintenance and rehabilitation in regions with wet-freeze climates. Based on a comprehensive literature review, in wet-freeze climate regions the recommendations are as follows: (1) use of warm-mix asphalt; (2) implementation of AASHTOWare Pavement ME Design approach, which can improve resistance to thermal cracking, fatigue cracking, and rutting; (3) development of a performance model and a standard design of perpetual pavement (3 distinct layers); (4) utilization of innovative materials (e.g., bio-derived binder, half warm-mix asphalt, sulfur-extended asphalt, PPA extenders, and fiber-modified asphalt); (5) application of intelligent compaction; and (6) implementation of HMA patching, including investigation of the microwave method for small-scale repair.

In 2016, Minnesota DOT [104] reported a reference for local agencies that have minimal knowledge of incorporating RAP material into new asphalt and would like to understand more. The most common maximum percent of RAP binder in local agencies in Minnesota was 30% of total binder. A high percentage of RAP binders can cause asphalt quality issues, such as decreasing the long-term performance and durability of asphalt pavement. Thus, the limitation of the amount of RAP can be the best way to control the quality and performance of asphalt mixtures (e.g., fatigue and thermal cracking) due to the variability and contamination issues of RAP. These issues can be caused by (1) removal process of RAP from an old roadway, (2) mix of surface and base courses, (3) collection of RAP from multiple sources, and (4) inclusion of waste trial batches of asphalt mixes. Therefore, the appropriate characterization of RAP materials is needed to ensure the RAP quality. This characterization includes measurements of asphalt content, extracted asphalt binder recovered, extracted aggregate gradation, and aggregate properties. It can be concluded that the quality control of RAP plays an important role in promoting use of RAP.

In Virginia DOT, the feasibility of RAP in road base and subbase layers was investigated to study the potential application of RAP for base or subbase for roadways [105]. The RAP stockpiles in Virginia have been continuously increased, despite the recycling efforts (maximum RAP content in asphalt mixture is 30%). A comprehensive review of the literature and state specifications was conducted. It was concluded that the use of RAP in road base and subbase layers is technically viable, but additional experimental validation will be needed for the 50% RAP asphalt mixes.

Similarly, in Wisconsin DOT, one research study currently in progress is also related to recycled asphalt materials (RAM) in HMA (Title: Recycled Asphalt Binder Study, PI: Carolina Rodezno, NCAT at Auburn University). Because of the advantages of decrease in cost, increase in rutting resistance, and the eco-friendly aspect, utilization of RAM has been widely investigated. This research focuses on (1) appropriate quantity and quality of RAM affecting performance of binders, (2) HMA performance tests, and (3) testing procedure to evaluate the quality of RAM and fresh/virgin asphalt binder blending.

To ensure the performance of asphalt mixture, the investigation of balanced mix design methods has been conducted. According to the *Balanced Mix Design Resource Guide* published by the National Asphalt Pavement Association [80], the performance-based asphalt mixture design approach has a high degree of innovation potential relying on mixture performance test results for design optimization compared to conventional volumetric design with performance verification (see **Figure 16**). The application of various performance tests during the mixture design allows the development of performance-based mixture optimization. Various performance testing methods adopted by agencies in the United States are summarized in **Table 45**.

Table 45. Performance testing methods for asphalt concrete (from [80])

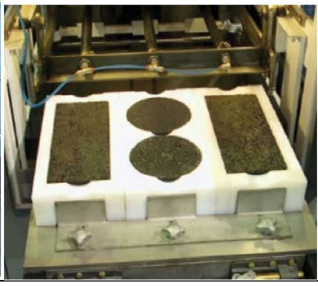
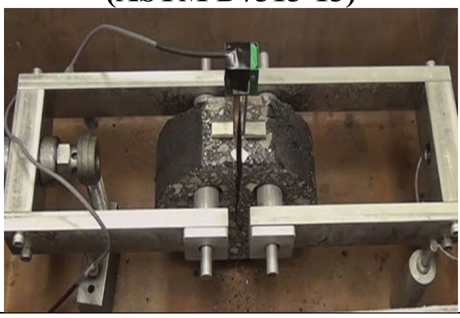
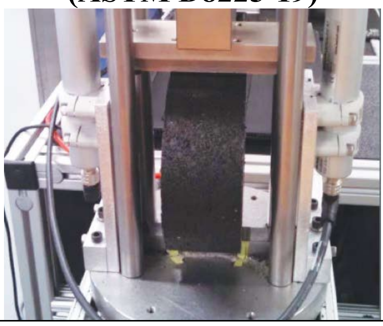
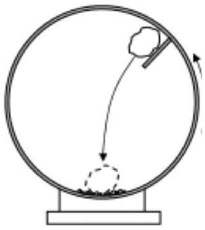
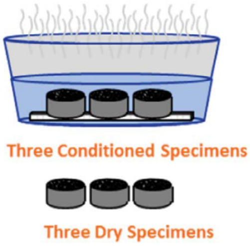
Name of test (Standard)	Adoption by agencies	Test results
Asphalt Pavement Analyzer (AASHTO T 340-10, 2019)  	Alaska, Alabama, Arkansas, **North Carolina**, New Jersey, South Carolina, South Dakota, **Virginia**	Rut depths
Hamburg Wheel-Tracking Test (AASHTO T 324-19) 	California, Georgia, Idaho, Iowa, Illinois, Kentucky, Louisiana, Massachusetts, Maine, Missouri, Montana, Oklahoma, Oregon, Tennessee, **Texas**, Utah, Vermont, Washington	Rut depths, stripping inflection point, creep slope, stripping slope, stripping number, stripping life, rutting resistance parameter
Disc-Shaped Compact Tension Test (ASTM D7313-13) 	Iowa, **Minnesota**, Missouri	Fracture energy
Indirect Tensile Asphalt Cracking Test (IDEAL-CT) (ASTM D8225-19) 	Alabama, Idaho, Kentucky, Missouri, Oklahoma, Tennessee, **Virginia, Texas**	Cracking test index (CT_{Index})

Table 45. Continued

Name of test (Standard)	Adoption by agencies	Test results
Overlay Test (NJDOT B-10, Tex-248-F) 	New Jersey, **Texas**	Number of cycles to failure (N_J), Critical Fracture Energy (G_c) (TX), Crack Resistance Index (B_{eta}) (TX)
Cantabro Test (AASHTO TP 108-14, 2020)  	**Virginia**	Percent abrasion loss
Tensile Strength Ratio (AASHTO T 283-14, 2018)  	Alabama, California, Colorado, Connecticut, Florida, Georgia, Illinois, Indiana, Kansas, Kentucky, Maryland, **Michigan**, **Minnesota**, Mississippi, Missouri, Montana, Nebraska, Nevada, New Hampshire, New Jersey, New Mexico, New York, **North Carolina**, North Dakota, Ohio, Oklahoma, Oregon, **Pennsylvania**, South Carolina, South Dakota, Tennessee, **Virginia**, Vermont, **Wisconsin**, Wyoming	Indirect tensile strength (IDT strength), TSR

3.7 Chapter Summary

This chapter provided a comparison of the current PennDOT Specifications with pertinent concrete and asphalt specifications of state highway agencies in Michigan, Minnesota, North Carolina, Texas, Virginia, and Wisconsin. Additionally, a survey of PennDOT and these six state DOTs was performed to inquire about relevant current issues that each DOT is facing as well as their design and construction specifications for concrete sidewalks and asphalt pavements.

Based on the information collected and analyzed in this chapter, the following conclusions can be drawn related to design and construction of concrete sidewalks and asphalt pavements:

- Conclusions related to mixture design and construction for concrete sidewalks:
  - PennDOT specifications for concrete mixture design and construction are well organized compared to the six other states.
  - Max. w/cm of concrete: PennDOT specifications allow concrete with w/cm up to 0.50 to be used for sidewalks. Other states with climate similar to or colder than Pennsylvania all had a lower max. w/cm, as low as 0.44.
  - Max. SCM dosage: PennDOT allows up to 35% fly ash and up to 65% slag in its concrete mixtures to mitigate ASR. Other states have a lower cap on their allowable SCM dosage such as 25% max. to 35% max. for fly ash and 30% max. to 50% max. for slag.
  - ASR mitigation protocols vary among the states and include both prescriptive and performance-based approaches.
  - Max. slump: While PennDOT allows up to 8 inches of slump with the use of high-range water reducers, other states specify lower allowable slumps, generally no more than 5 inches.
  - Min. compressive strength: Most states have a min. 28-day compressive strength of 2,500 to 3,500 psi while Minnesota requires a 4,500 psi concrete at 28 days.
  - The survey results suggested the following parameters as important contributors to surface scaling of concrete: Hand-finishing and over-finishing of the surface; SCM-rich mixtures; poor curing; inadequate application of curing compound.
  - Also, the following strategies are used by the state DOTs to mitigate scaling: Mandating proper curing method and duration; limiting the amount of chert, lightweight and deleterious pieces in aggregates; specifications allowing 5 years to file a claim against a contractor for workmanship defects; proper air entrainment.

- Conclusions related to mixture design and construction for asphalt pavements:
  - Overall, current PennDOT specifications for design of asphalt mixture and its construction are well organized in comparison to specifications in other states.
  - Almost every state surveyed reported that cold weather paving is a challenge and can result in problems needing special attention.
  - Measures taken by states for cold weather paving include insulated trucks, higher mix temperatures, thicker layers, and using warm-mix asphalt additives.
  - Paver-mounted thermal imaging is used by two of the surveyed states and is recommended as a very useful tool to monitor the pavement temperature differences with respect to thermal segregation in cold weather paving.
  - The minimum required surface temperature for paving in some states is tied into factors such as the amount of material being placed, the performance grade of the binder, and the traffic level.
  - It is mostly observed that the states are moving toward reduction of the number of asphalt mix categories and gyration levels in the Superpave Gyratory Compactor at the design stage.
  - It is also concluded that most of the surveyed states are moving toward the use of performance tests at the design and production stage.
  - The surveyed states have either implemented or intend to implement reclaimed binder ratio in their specifications instead of specifying the amount of RAP or RAS in the mix. The maximum allowed RAS is limited to 5% in all surveyed states. The

RBR varies in the range of 0.15 to 0.45 depending on the state, the binder grade, the mix type, the paving layer, and whether RBR is coming from RAP, RAS, or a combination.

Chapter 4. Review of Past PennDOT Specifications

4.1 Introduction

This chapter investigates the limitations and concerns – related to design and construction of concrete sidewalks and asphalt pavements – that have been identified by PennDOT since publication of its Construction Specifications, Publication 408/2016-IE. This was done by a review of relevant PennDOT specification changes as well as strike-off letters since the release of the 408/2016-IE document. As such, this chapter provides a summary table of the relevant PennDOT specification changes in chronological order with explanation of the reasons for these changes. The scope was limited to concrete sidewalks and pavements as well as asphalt pavements.

4.2 PennDOT Specifications Related to Concrete Sidewalks

Table 46 provides a summary of the PennDOT specification changes related to design and construction of concrete pavements and sidewalks since Publication 408/2016-IE. It is observed that, in recent years, PennDOT has significantly improved and tightened its specifications for concrete pavements (it also did so for bridge decks, but that is outside the scope of the current study). The most significant specification changes are listed below:

- PennDOT now requires optimizing aggregate gradation for concrete pavements. To facilitate compliance with this new requirement, PennDOT allows the use of AASHTO No. 467 coarse aggregates for concrete mixtures and has removed the requirements for coarse aggregate content of concrete mixtures.

- PennDOT has raised the quality requirements for Class AA concrete (for pavements) by reducing the maximum allowable w/cm and increasing the minimum required 28-day compressive strength. Additionally, new requirements for maximum permeability and shrinkage of concrete pavement mixtures have been added. The authors recommend that PennDOT consider adopting similar requirements for concrete sidewalks.

- PennDOT has expanded the requirements for construction and curing of concrete pavements. These include expansion of the field operation quality control (QC) plan, limiting the allowable water evaporation rate during construction, and disallowing the use of steel or Fresno floats or adding water or monomolecular film to the concrete surface to assist in finishing. The authors recommend that PennDOT consider adopting similar requirements for concrete sidewalks.

- For sidewalks, water curing or curing by membrane-forming curing compounds is required to be performed for a minimum of 7 days. However, this requirement is included in section 1001.3(p), which primarily discusses curing of bridge elements, and does not specifically mention sidewalks. As such, there is a risk that this specification language may be overlooked for sidewalks. At the conclusion of curing, boiled linseed oil must be applied to the entire surface of the concrete sidewalk.

- Protocols for determining aggregate reactivity and preventive measures against alkali-silica reaction have been substantially revised to be more compatible with the AASHTO R 80 document [106]. While the authors fully endorse this change, it is their opinion that this has led to an increased use of SCMs in concrete mixtures, which increases the susceptibility of concrete to surface scaling as discussed in Sections 2 and 3. As such, guidance or mandate should be provided to contractors for limiting the maximum SCM content of concrete mixtures and for developing plans to mitigate set retardation and to ensure proper construction and curing of SCM-rich concrete mixtures.

In chapters 2 and 3, several concrete mix design parameters as well as construction and curing parameters were identified that have significant impact on the susceptibility of concrete flatwork (such as sidewalks) to deicing salt scaling. These are listed in **Table 48** and **Table 49** along with any changes in the governing PennDOT specifications since 2016. The proposed limits by the authors based on the findings of Tasks 1 through 4 of this project are also included. As a reminder, Publication 408/2016-IE was the governing specifications for the construction of concrete sidewalks on the Wilkes University campus in Luzerne County, PA.

<u>Strike-off letters</u>

In this chapter, active and inactive strike-off letters (SOL), which were issued since 2016 and are relevant to design and construction of concrete pavements and sidewalks, are discussed. The information of letter number, subject, issue date, and a brief summary are included.

- Inactive Strike-off letter (481-18-05)
  Subject: ASTM D6690 Type IV Joint Sealant Material Implementation
  Issue date: 10/5/2018
  Deactivation date: 04/08/2019
  The intent of this SOL was to implement a revision to Publication 408, Section 705.4(b) Rubberized Joint Sealing Material specification. The revision required ASTM D6690 Type II sealants to be used for sealing asphalt pavement joints and ASTM D6690 Type IV sealants for all other joint sealing applications. This revision was in response to a recommendation provided during the recent ACPA Concrete Pavement Tour/Meeting to mitigate premature failures of concrete pavement joint seals using the Type II sealants. The Type IV sealants are more forgiving and expected to provide better performance. Section 705.4(b) previously required the use of Type IV sealing material. This revision was incorporated in Pub. 408/2016 Change No. 6 effective April 5, 2019. The revision was initially implemented via the Standard Special Provision (a00057 Changes to Specifications: Section 705) on all projects let on or after October 19, 2018.

- Inactive Strike-off letter (482-18-02)
  Subject: Alkali-Silica Reactivity (ASR) Mitigation
  Issue date: 02/22/2018
  Deactivation date: 10/18/2018
  This SOL was proposed to establish the policy and procedure with respect to the Pub 408, Section 704, ASR Mitigation, which was suggested by the Bureau of Project Delivery, Plans, Schedules, Specifications and Constructability Section. The revisions were reflected in the next change to Pub 408 (2016-5), and initially issued as a Standard Special Provision (C -a00046-A Changes to Specifications: Sections 701, 704 and 724), with instructions that it be included in all projects let after April 1, 2018.

- Inactive Strike-off letter (481-16-03)
  Subject: Concrete Core Compressive Strength Testing
  Issue date: 4/20/2016
  Deactivation date: 06/15/2018
  The purpose of this SOL was to provide clarification of documentation requirements as they relate to the previously issued SOL, 481-15-02, dated January 21, 2015, which provided guidance for sampling, packaging, and transporting concrete cores for compressive strength testing. Following the issuance of SOL 481-15-02, a workgroup comprised of FHWA, industry and Department members was formed to review AASHTO T 24 [107] and other research and standards related to testing concrete cores. As a result, Pennsylvania Test Methods (PTM) 606 was revised and implemented to replace AASHTO T 24 [107]. Specification revisions were made to Section 110.10(a) and several other sections in Publication 408 where AASHTO T 24 was previously referenced. These revisions were released to the Districts on February 4, 2016, as change a00023 for projects let after March 18, 2016.

Table 46. Summary table of relevant PennDOT specification changes in chronological order with explanation on the reasons for the changes (Reference: Publication 408/2016-IE)

Section and Portion Changed		Revised w/ Change No.	Effective Date	Explanation of Change
Section	Part or Paragraph			
501	501.4(a), 501.4(b)	2020-2	April 9, 2021	1. To increase payment for defective concrete and defective concrete pavement left in place from 5% to 50%.
501	501.2(a)	2020-IE	April 10, 2020	1. Requirement for coarse aggregates for concrete pavements has been revised to allow AASHTO No. 467 and to limit the absorption of aggregates to 3.0% for gravel and to 2.0% for all other aggregates. 2. Mix design parameters for concrete pavements have been revised as shown in Table 2. This includes reducing the maximum w/cm from 0.47 to 0.42 or 0.45 and increasing this minimum 28-day mix design compressive strength from 3,750 psi to 4,000 psi. 3. Concrete pavement mix designs must be performed according to PTM No. 529 to determine the optimized aggregate gradation. 4. Requirements for maximum allowable permeability and shrinkage have been added for concrete pavements. 5. The target plastic air content has been increased to 7.0%±1.5%.
501	501.3	2020-IE	April 10, 2020	1. Requirements for field operation QC plan have been expanded. 2. Concrete pavements must not be placed when the evaporation rate exceeds 0.20 lb/ft^2hr unless mitigation measures such as use of windbreaks or fog misting are employed. 3. Do not add water or monomolecular film to the concrete surface to assist in finishing. Do not over finish. Do not use steel or Fresno floats. 4. The length of curing has been revised from 96 hours to the time at which the pavement has achieved sufficient strength for opening to traffic as specified in Section 501.3(q). Curing must start after finishing and texturing, and within 30 minutes of the dissipation of bleed water. 5. Cold weather curing protocol has been extended and includes the use of insulating blankets when the pavement depth is less than 6 inches.
676	676.3	2020-IE	April 10, 2020	1. Apply boiled linseed oil to the entire surface of the concrete sidewalk as specified in Section 1019.3(a). If curing was performed with a membrane-forming curing compound, remove the curing compound before placing the boiled linseed oil. 2. For sidewalks and driveway aprons through driveways, place welded wire fabric reinforcement made of W4 or W4.5 wire at 6-inch centers transversely and longitudinally conforming to ASTM A 1064 at half-depth of concrete.

Table 46. Continued

Section and Portion Changed		Revised w/ Change No.	Effective Date	Explanation of Change
Section	**Part or Paragraph**			
701	701.1(b)1 and 701.1(b)2	2016-5	October 6, 2018	1. References new forms that must be submitted by cement supplier to PennDOT to verify cement alkali content and other limits for portland cement.
704	704.1	2020-IE	April 10, 2020	1. The allowable range for the coarse aggregate content of concrete mixtures has been removed from 704.1(b) Table A. 2. The phrase "Pozzolan" has been renamed to "Supplementary Cementitious Material (SCM)." Metakaolin had been added under 704.1(g) as an acceptable SCM. 3. Class AAAP-LW (lightweight) has been added for bridge decks, and class AA-LW and class ASC (accelerated structural concrete) have been added for Structures and Misc. Protocol for design of lightweight mixtures is included. 4. Criteria for design of sulfate resistant concrete have been added. 5. The slump upper limit of AAAP mixes is specified as 5.5 inches regardless of admixtures used.
704	704.1(c)2, 704.1(d)4.b, 704.1(d)5, 704.1(g)1.b, 704.1(g)1.b.1, 704.1(g)1.d, and 704.1(h)	2016-5	October 6, 2018	1. To determine aggregate reactivity and preventive measures for Alkali Silica Reaction. A complete overhaul of the protocol for mix design using potentially ASR reactive aggregates is provided.
724	724.2(b), 724.3, 724.4, and 724.5	2016-5	October 6, 2018	1. References new forms that must be submitted by pozzolan supplier to PennDOT to verify alkali content and other limits for concrete pozzolans.
1001	1001.2(b), 1001.3(k)6, 1001.3(p)3, 1001.3(q)1, 1001.3(q)2.c, 1001.3(u), and 1001.4(i)	2016-4	April 6, 2018	1. Curing by Membrane-Forming Curing Compound: Protect the curing membrane against damage for a minimum of 7 days. Re-apply an additional coat of curing compound to any damaged areas. Should the curing membrane be subjected to continuous damage, the Representative may limit work on the deck until the 7-day period is complete. Reduction of the 7-day period will not be allowed under any circumstance. 2. Protocol to protect bridge deck concrete against rain before initial set is provided. 3. The allowable evaporation rate for bridge decks is decreased from 0.15 to 0.06 lb/ft^{2}hr to mitigate plastic shrinkage cracking. 4. Water curing must be maintained for a minimum of 7 days. However, bridge decks (made with class AAAP mix) must be cured for a minimum of 14 days followed by a 7-day liquid membrane (curing compound) cure. Approach slabs must be water cured for a minimum of 7 days, followed by a 7-day liquid membrane cure for approach slabs constructed with AAAP.

Table 47. Mix design criteria for concrete pavements (From: Publication 408/2020-2, Section 501)

Class of concrete	Use	Cement factor (lb/yd^3)	Water cement ratio$^{(1)(2)}$	Minimum mix design compressive strength (psi)			Proportions coarse aggregate solid volume (ft^3/yd^3)	28-day structural design compressive strength (psi)
				3 days	7 days	28 days$^{(3)}$		
AA	Slip form paving	517–611	0.37–0.42	-	3,000	4,000	-	3,500
AA	Form paving	517–611	0.37–0.45	-	3,000	4,000	-	3,500
AA	Accelerated paving$^{(4)}$	517–752	0.37–0.45	-	3,000	4,000	-	3,500
HES	Paving	517–752	0.37–0.42	2,000		4,000	-	3,500

(1) Where the cement is replaced by supplementary cementitious material, use a water to cement plus supplementary cementitious material ratio by weight.

(2) Lower Cement Factor can be permitted by DME/DMM if the mix design is demonstrated to perform adequately.

(3) DME/DMM may accept mix designs based on the 56-day strength based on qualification testing.

(4) For accelerated cement concrete, submit a mix design as specified in Section 704.1(c) having a minimum target value compressive strength of 1,500 pounds per square inch at 7 hours when tested according to PTM No. 604. The minimum required compressive strength for opening an accelerated strength pavement to traffic is 1,200 pounds per square inch as specified in Section 501.3(q).

Table 48. Specification requirements on mix design for concrete sidewalks

PennDOT Pub 408 Specifications	Aggregates	w/cm range	Cementitious material factor	SCM range	ASR mitigation protocol	Slump	Plastic air content	Proportion coarse aggregate solid volume	Compressive strength
Concrete used for sidewalks on Wilkes Univ.	Fine: Type A Coarse: Type A #57	0.45–0.48 Class A Concrete	580 lb/yd^3	Slag: 232 lb/yd^3 (40% of CM)	-	3.75–6”	4.6 – 6.8%	10.40 ft^3/yd^3	> 3,210 psi at 7 d > 5,474 psi at 28 d
2016-IE (Governing specs. for Wilkes Univ. project)	Fine: Type A Coarse: Type A #57, #67, #8	Max. 0.50 Class A concrete to be used for sidewalks	564–752 lb/yd^3	Fly ash: Min. 15% Slag: 25–50%	Fly ash: 15–25%, Min. 20% if AASHTO T303 > 0.40% Slag: 25–50%, Min. 40% if AASHTO T303 > 0.40% Silica fume: 5–10%	Max slump: w/o WR: 5” w/ WR 6 ½” w/ HRWR: 8”	6.0%±1.5%	10.18–13.43 ft^3/yd^3	7-day Min. 2,750 psi 28-day Min. 3,300 psi
Has this changed since 2016?	Yes, since 2020-IE, #467 is also allowed as coarse aggregate	No	No	Yes, since Feb. 2018, SCM dose is determined based on ASR mitigation: Fly ash: Max. 35% Slag: Max. 65% Silica fume: 2.4 × cement factor × alkali content	Yes, via strike-off letters in Feb. 2018 and subsequently in Pub 408/2016-5, a complete overhaul of the protocol for mix design using ASR reactive aggregates was provided.	No	No	Yes, removed since Pub 408/2020-IE	No
Proposed limits	Same as Pub 408/2020-2. Optimizing aggregate gradation is encouraged.	Max. 0.45 Class AA (form paving) concrete to be used for sidewalks	517–611 lb/yd^3	Same as Pub 408/2020-2 but discouraging the use of SCM beyond dosages needed for ASR mitigation	Same as Pub 408/2020-2	Max slump: 5” regardless of admixture	7.0%±1.5%	None	7-day Min. 3,000 psi 28-day Min. 4,000 psi

Table 49. Specification requirements on construction of concrete sidewalks

PennDOT Pub 408 Specifications	Allowable ambient temperature	Concrete temperature at the time of placement	Finishing	Curing method	Curing duration
Concrete used for sidewalks on Wilkes Univ.	-	68–81 °F	Unknown	Unknown	Unknown
2016-IE	> 40 °F	50–90 °F	Machine or manual strike-off and consolidation, followed by floating and a final broom finish.	Water curing or liquid membrane-forming curing compound	7 days
Has this changed since 2016?	No	No	Yes, in Pub 408/2020-IE language was added to disallow adding water or monomolecular film to the concrete surface to assist in finishing, and to disallow over-finishing or use steel or Fresno floats for finishing.	No	Strengthened in 2020-IE by requiring boiled linseed oil to be applied to the entire surface of concrete sidewalk after the 7-day curing
Proposed limits	Same as Pub 408/2020-2	Same as Pub 408/2020-2	Pub 408/2020-2. Additionally, limit the evaporation rate to 0.20 lb/ft^2hr unless mitigation measures such as use of windbreaks or fog misting are employed.	Same as Pub 408/2020-2	Same as Pub 408/2020-2

4.3 PennDOT Specifications Related to Asphalt Pavements

Table 50 provides a summary of the PennDOT specification changes related to design and construction of asphalt pavements since Publication 408/2016-IE. As a reminder, Pub 408/ 2016-5 was the effective specification for the construction of asphalt pavements on state roads 1016 and 2020 in Lackawanna County. **Table 50** indicates several major changes in asphalt-related specifications of Pub 408 within the last 5 years, albeit not directly related to the issues encountered in construction of SR 1016 and SR 2020 in District 4. The most significant specification changes are listed below. Details of when these changes occurred and which specific section of the specifications they relate to can be found in **Table 51** and **Table 52**.

- PennDOT has moved away from using terminology of "hot mix asphalt" versus "warm mix asphalt" and is using the term "asphalt mixture." However, the specifications refer to Warm Mix Asphalt (WMA) technology additives or modifiers used in asphalt binders.

- As a result of not separating asphalt into hot mix and warm mix categories, PennDOT has merged corresponding specification sections into a single section. Sections 309 (Superpave hot mix asphalt for base course) and 311 (warm mix asphalt for base course) have been merged into new section 313 (Superpave asphalt mixtures for base courses). Similarly, sections 409 (Superpave hot mix asphalt for binder and surface courses) and 411 (Superpave warm mix asphalt for binder and surface course) have been merged into new section 413 (Superpave plant-mixed asphalt courses).

- Pervious Asphalt Pavement Systems were brought into specifications and allowed on the Department projects.

- Ultra-thin bonded wearing courses were brought into specifications for use on roads and bridges.

- Use of antistrip additives became mandatory for all asphalt mixes to guard against stripping and moisture damage. The antistrip additive could be already built into the WMA technology additive or applied separately.

- Use of fine Superpave asphalt mixes with Nominal Maximum Aggregate Size (NMAS) of 4.75 mm became part of specifications.

- It became permissible to use WMA technology additives with Stone Matrix Asphalt (SMA).

- Several sections dealing with conventional asphalt mixes (FJ-1, FJ-1C, FB-1 for binder and wearing courses, and FB-2 for binder and wearing courses) were removed from Pub 408.

- Major improvements were made in tack coat specifications. For one, diluted asphalt emulsion tacks (AET) were removed from tack application and replaced by regular emulsion to expedite the curing rate. Non-tracking tacks were also added. Finally, an important change was to revise the emulsion application rates based on the surface texture (newly paved, old pavement, concrete base, milled surface).

- Superpave plant mixed asphalt with NMAS of 6.3 mm was added to specifications for thin lift applications (thickness of 3/4” to 1¼”).

- There were major changes made in connection with weather and seasonal limitations. Two groups of mixes were considered. For more sensitive mixes (see details in specifications), placement is allowed between April 1 through October 15. For other mixes, it is allowed between April 1 and October 31. If extended season paving is permitted, it can take place between April 1 through November 15 for group 1 and from March 1 through December 15 for group 2. Special requirements are attached to extended paving. For example, there will be a spring evaluation and manual survey by the Department to be conducted by May 1.

While PennDOT has made significant improvements in the asphalt-related specifications within the last 5 years, there are a few specific areas that may need attention during the next round of changes of specifications. Some of these areas were covered in Chapter 3 of this research project and submitted to PennDOT previously. Of specific concern is cold weather and extended season paving. It may be prudent to revisit and tighten specifications related to this type of paving. For example, as recommended in Chapter 3, for some mixes, use of thermal imaging may be appropriate to ensure mix temperature uniformity.

<u>Strike-off letters</u>
In this Chapter, active and inactive strike-off letters, which are related to design and construction of asphalt pavements, are summarized. The information of letter number, subject, issue date, and a brief summary are included.

- Active Strike-off letter (481-20-03)
  Subject: New Publication 2, Section C.4.8, Asphalt Temperature Checks Taken from Hauling Equipment at the Project Site
  Issue date: 08/12/2020
  The intent of the SOL was to suggest a guidance of the measurement of asphalt temperature taken from hauling equipment at the project site. In the Project Office Manual, a section related to the guidance on how to evaluate temperatures of asphalt mixtures in the field was not included. Section C.4.8, Asphalt Temperature Checks Taken from Hauling Equipment at the Project Site was created via Clearance Transmittal C-20-002 to provide the guidance. This policy was effective in Publication 2, Change No. 1, April 2020 Edition.

- Active Strike-off letter (495-17-04)
  Subject: Milled Material Retainage and Use
  Issue date: 03/10/2017
  The intent of this SOL was to address the retention of milled materials and their use in RAP mixes. In addition, a requirement of a minimum percentage of the milled materials in asphalt mixtures was established. This policy was valid after April 6, 2017. The minimum quantity of milled materials to be retained was set at 15% of the total quantity of milled material for the project. A higher percentage of materials could be considered if asphalt mixtures containing higher volumes of RAP were suggested. Similarly, there was a deactivated strike-off letter (495-17-2), “Milled Asphalt Pavement Material: Retainage, Plan and Use.” This strike-off letter was effective on Jan. 26, 2017 and deactivated on Aug. 9, 2018.

- Active Strike-off letter (481-16-06)
  Subject: Implementation of Cost Benefit Analysis of Anti-Strip Additives in Hot Mix Asphalt with Various Aggregates Research
  Issue date: 10/28/2016
  The intent of this SOL was to adjust the recommendations of the report "Cost Benefit Analysis of Anti-Strip Additives in Hot Mix Asphalt with Various Aggregates." All asphalt mixtures approved after December 30, 2016 were required to incorporate a minimum dosage of anti-strip agent specified in Bulletin 27, Chapter 2A and 2B. Minimum content of anti-strip agent for WMA was removed from Pub 408, Section 411 and 311. In accordance with Bulletin 27, all HMA/WMA were evaluated. If asphalt mixtures contained moisture-susceptible coarse or fine aggregates, they were required to be evaluated for the moisture susceptibility or treated with a higher content of anti-striping agent.

- Active Strike-off letter (481-16-04)
  Subject: Bituminous Job Mix Formula (JMF) Submissions
  Issue date: 07/13/2016
  This SOL was suggested to revise Bulletin 27, Bituminous Concrete Mixtures, Design Procedures, and Specifications for Special Bituminous Mixtures, Appendix J, Chapter 2A and Chapter 2B. Bulletin 27 revisions resulted in reducing the number of asphalt mixture designs, which are submitted annually for review and approval. This SOL also included a standardized JMF naming system in Bulletin 27, which are currently listed in Appendix K. This policy was implemented on the effective date of this SOL.

- Active Strike-off letter (481-18-02)
  Subject: Revision of Section 470 Seal Coat Specification, Addition of Section 472 Fog Seal Specifications and Rewrite of Bulletin 27 Appendix E Pennsylvania Design Method for Seal Coats and Surface Treatments
  Issue date: 02/12/2018
  The intent of this SOL was to adjust changes in the design of seal coat and its application process. In addition, the implementation of a new specification related to the application of a fog seal over new seal coat treatments was included. The major changes specified in Section 470 were a preference to use polymer-modified emulsions, the option to use high float emulsions, the addition of a more cubical seal coat aggregate option, and enhanced seal coat compaction requirements between the wheel paths. In Section 472, the utilization of fog sealing bituminous seal coats within 45 days of pavement placement was allowed. It was believed that this change would be beneficial for improving the performance of seal coat treatment. These changes to Bulletin 27 and Bulletin 25 were effective immediately.

- Inactive Strike-off letter (481-17-01)
  Subject: Bituminous Tack Coat Specification Revisions Publication 408, Section 460 and Bulletin 25 Specifications
  Issue date: 02/01/2017
  Deactivation date: 12/05/2018
  This SOL was proposed to implement revisions to Pub 408, Section 460, Pub 37, Bulletin 27 for bituminous tack coat. In Pub 408, Section 460, emulsified asphalt and Class AE-T material are removed. Tack and NTT/CNTT were newly added. In Bulletin

25, specifications related to TACK and NTT/CNTT were included. The revisions related to the construction were effective in Pub 408/2016-2, April 7, 2017.

Table 50. Summary table of relevant PennDOT specification changes in chronological order with explanation on the reasons for the changes (Reference: Publication 408/2016-IE)

Section and Portion Changed		Revised w/	Effective	Explanation of Change
Section	Part or Paragraph	Change No.	Date	
311	311.1, 311.2, 311.3, 311.3(a), (b), & (c), 311.4 and 311.4(a)1	2016-2	April, 7, 2017	To remove information that is covered in Section 411 and to reference Section 411 instead.
409	409.2(b)1, 409.2(e)1.d.5 Table B, 409.2(f)2, 409.2(f)2.b, 409.3(f), 409.3(j)1, and 409.4(a)3	2016-3	October 6, 2017	Aggregates having nominal maximum aggregate size of 4.75 were allowed to be used.
409	409.2(f)2, 409.3(j)2, 409.3(j)3, 409.3(b), and 409.3(j)4.a	2016-6	April 5, 2019	The paving season was extended with Department approval.
409	409.3(g)1, 409.3(h)1.b, 409.3(h)2.a, Table G, 409.3(k)3	2016-7	October 4, 2019	To include revisions to tack coat materials, change minimum depth of 12.5 mm course material for pavement cores, and clarify timing and terminology of work stoppages.
409		2020-IE	April 10, 2020	Section 409 was removed.
411	411.1, 411.2(e)1, 411.2(e)1.a.3, 411.2(e)1.d.6, 411.2(e)Table A, 411.2(h), 411.2(j), 411.3(a)1, 411.3(c)1, and 411.3(c)2	2016-2	April 7, 2017	To implement the findings of the research report “Cost Benefit Analysis of Anti-Strip Additives in Hot Mix Asphalt with Various Aggregates” by mandating a minimum dosage of anti-strip to all asphalt mixtures and revise the design ESAL range guidance to Districts to allow Districts to bump design ESAL levels in order to enhance asphalt durability.
411		2020-IE	April 10, 2020	Section 411 was removed.
413		2020-IE	April 10, 2020	Section 413 is newly added in Pub 408/2020-IE. Section 413 covers specifications included in Section 409 and 411.
419	Title, 419.1, 419.2(a)1, 419.2(b)2, 419.2(e)1, 419.2(e)1.a, 419.2(e)1.c, 419.2(e)1.d, 419.2(e)1.d.3, 419.2(e)1.d.7, Table D, 419.2(g), 419.2(h), 419.2(i), 419.2(j), 419.3(a), 419.3(c), 419.3(i)2.a, Table F, 419.3(i)2.b, 419.3(i)2.c.1, 419.3(k), 419.4(a)3, 419.4(a)3.b, and Tables G, H, and I	2016-3	October 6, 2017	To incorporate Warm Mix Asphalt (WMA) technology into Stone Matrix Asphalt (SMA) Mixture Design.

Table 50. Continued

Section and Portion Changed		Revised w/ Change No.	Effective Date	Explanation of Change
Section	**Part or Paragraph**			
419	419.1, 419.2(e)1, 419.2(f)1, 419.3(c), 419.3(c)4, 419.3(g), 419.3(i)1, 419.3(i)2, 419.3(k), 419.4(a)3	2020-2	April 9, 2021	To allow the use of Hands On Local Acceptance (HOLA) acceptance with Stone Matrix Asphalt.
460	460.2(a), Table A, 460.3(a), 460.3(b), Table B, and 460.3(c)	2016-3	October 6, 2017	To allow a new tack coat material that contains half of the water that the current AET contains and therefore will cure faster. Also a nontracking tack coat specification has been added and additional changes to update application rates to account for variable surface textures that are encountered in the field.
702	702.1(a), 702.1(b), 702.1(c)	2020-IE	April 10, 2020	1. QC plan for the annual review can be submitted to the LTS until the beginning of each calendar year before shipping material to the project or March 31. 2. QC plan for PG binder and emulsified asphalt are specified: AASHTO R 26 and Bulletin 25 for PG asphalt binder; AASHTO R 77 and Bulletin 25 for emulsified asphalt. 3. In Section 702.1(b) Certification, the amount of each sample for the tests according to Bulletin 25 are updated. In addition, Certificate of Compliance (Form CS-4171) should be signed by a responsible company. It includes type of material, tank number, and company lot number. 4. In Section 702.1(c) Handling and Transportation, the information that should be included in vendor's bill of landing is updated with respect to emulsified asphalt, non-polymer-modified PGAB, and polymer-modified PGAB.
703	Table B and Table C	2016-4	April 6, 2018	1. Adds AASHTO No. 89 and No. 9 graduations in order to establish quality parameters for finer aggregates that are currently available and to facilitate the new 6.3 mm mix type in new Section 412. 2. Also, provides requirements for Type S coarse aggregate with reference to AASHTO T 103 for freezing and thawing of aggregate in water.

Table 51. Requirements of material properties for asphalt pavements (asphalt mixtures comparable with asphalt used on SR1016 and SR2020, ESALs = 0.3 – 3 & Nominal aggregate size = 9.5 mm)

PennDOT Pub 408 Specifications	Design million ESALs	Nominal max. agg.	PG-Binder	Compaction level & Density requirements			Dust (or fines)-to-binder ratio	Volumetric properties			Ratio RAP or RAS to mixture	Tensile strength ratio
				N_{ini}	N_{des}	N_{max}		VMA at N_{des}	Air voids at N_{des}	VFA		
Asphalt used on SR1016 and SR2020	0.3–3	9.5 mm	PG 64-22	7	75 95.9%	115	0.8	16.8%	4%	76.0%	20% RAP Actual 20% RAP in the mixture	98%
2016-IE	0.3–3 (Bulletin 27)	9.5 mm (Bulletin 27)	-	7 90.5% (Bulletin 27)	75 96.0% (Bulletin 27)	115 98.0% (Bulletin 27)	0.6–1.2 (Bulletin 27)	15.5% (Bulletin 27)	4.0% (Bulletin 27)	65–78% (Bulletin 27)	5–15% RAP or 5% RAS, > 15% RAP or 5% RAS + > 5% RAP (409)	-
2016-5 (Governing specs. for SR1016 and SR2020 projects)	Same	Same	-	Same	Same	Same	Same	Same	Same	Same	Same	-
Has this changed since 2016?	No	No	No	No	No	No	No	No	No	No	No	-
Proposed limits	Even though current volumetric properties-based asphalt mixture design would be fine, the research team recommends PennDOT to adopt balanced mix design (BMD) method, which is performance tests-based asphalt mixture design criteria.											

*Bulletin 27 Jan. 2003 Edition change 5 has been effective since January 19, 2011

Table 52. Requirements of asphalt pavement placement (asphalt mixtures comparable with asphalt used on SR1016 and SR2020, ESALs = 0.3 – 3 & Nominal aggregate size = 9.5 mm)

PennDOT Pub 408 Specifications	**Tack coat**	**Placement temperature (min. air & surface temp.)**	**Extension of construction period**
Asphalt used on SR1016 and SR2020	-	Air temp: 28.9–73.3F	Placed in October – early November 2019
2016-IE	Emulsified asphalt, Class AE-T specified in Bulletin 25 Application rate: 0.02–0.07 gal/yd^2 Air temperature: > 40F (460)	Air or surface temperature: > 40F Apr. 1–Oct. 31 (409.3(b))	Mar. 20–Nov. 20 (409.3(b))
2016-5 (Governing specs. for SR1016 and SR2020 projects)	**Application temperature** Tack: 90–150F NTT/CNTT: 140–180F **Asphalt residual rates** New bituminous paving: 0.03–0.05 gal/yd^2 Existing bituminous paving: 0.04–0.07 gal/yd^2 Milled surface: 0.04–0.08 gal/yd^2 Air temperature: > 40F (460)	Same	Same
Has this changed since 2016?	Yes, in 2016-3 this was revised to: **Application temperature** Tack: 90–150F NTT/CNTT: 140–180F **Asphalt residual rates** New bituminous paving: 0.03–0.05 gal/yd^2 Existing bituminous paving: 0.04–0.07 gal/yd^2 Milled surface: 0.04–0.08 gal/yd^2 Air temperature: > 40F (460)	Yes, in 2016-6 this was revised to: Air or surface temperature: > 40F Apr. 1–Oct. 15 for wearing courses Apr. 1–Oct. 31 for all other courses (409.3(b))	Yes, in 2016-6 this was revised to: Apr. 1–Nov. 15 for wearing course Mar.1–Dec. 15 for all other courses (409.3(b))
Proposed limits	Same as Pub 408/2020-2	The application of thermal imagining system in extended season paving can be considered to ensure the uniformity of mixture temperature after the placement.	

In the preceding section, a review is presented of some of the asphalt design and construction parameters in terms of any changes in specifications since Pub 408/2016-IE.

Aggregates

Size and quality requirements for fine and coarse aggregates have not been changed between Pub 408/2016-IE and 408/2020-2. Aggregates should conform to the quality requirements for Superpave asphalt mixture design as specified in Bulletin 27. The quality requirements for coarse aggregates have not been changed since Pub 408/2016-IE. The quality requirements for Type A coarse aggregates are summarized in PennDOT Specifications Section 703.2, which is also discussed in the next section in terms of aggregates for asphalt pavements.

According to AASHTO M 323 [61], the combined aggregates should have a nominal maximum aggregate size of 4.75 mm to 19.0 mm for asphalt pavement surface courses and smaller than 37.5 mm for asphalt pavement subsurface courses. In Bulletin 27 2A, the combined aggregate requirements were revised from what is specified in AASHTO M 323 Table 6 [61].

Volumetric properties

Volumetric properties depend on design ESALs and should meet the requirements specified in Bulletin 27 Chapter 2A. The latest version of Bulletin 27 2A is Change 5, which has been effective since January 19, 2011. Therefore, there have been no changes in requirements for design parameters and volumetric properties of asphalt mixtures since the time of mix placement on SR 1016.

Composition tolerance requirements of asphalt mixtures are listed in **Table 53**, as extracted from Sections 409 and 413 of Pub 408. The requirements for asphalt mixture temperature were revised in Pub 408/2020-IE compared to what was reflected in Pub 408/2016 Editions. Class of materials was also revised.

Table 53. Job mix formula: Composition tolerance requirements of the mix

	Single sample (n = 1)	Multiple samples (n ≥ 3)
Gradation		
Passing 12.5 mm and larger sieves	± 8%	± 6%
Passing 9.5 mm to 150 μm sieve	± 6%	± 4%
Passing 75 μm sieve	± 3.0%	± 2.0%
Asphalt content		
19.0 mm asphalt mixtures and smaller	± 0.7%	± 0.4%
25.0 mm asphalt mixtures and larger	± 0.8%	± 0.5%

Temperature of mixture (°F)

Specification	**Class of material**	**Type of material**	**Minimum**	**Maximum**
Pub 408/2016 IE–Change 7 (Sec 409 HMA)	PG 58-28	Asphalt cement	260 °F	310 °F
	PG 64-22	Asphalt cement	265 °F	320 °F
	PG 76-22	Asphalt cement	285 °F	330 °F
	All other PG binders	Asphalt cement	Specified in Bulletin 25	Specified in Bulletin 25

Specification	**Class of material**	**Type of material**	**Chemical, organic, foaming additives minimum**	**Mechanical foaming equipment/ process minimum**	**Maximum**
Pub 408/2016 IE–Change 7 (Sec 411 WMA)	PG 58-28	Asphalt cement	215 °F	230 °F	310 °F
	PG 64-22	Asphalt cement	220 °F	240 °F	320 °F
	PG 76-22	Asphalt cement	240 °F	255 °F	330 °F
	All other binders	Asphalt cement	The higher of 215 °F or the minimum temp. specified in Bulletin 25 minus 45	The higher of 230 °F or the minimum temp. specified in Bulletin 25 minus 30	Specified in Bulletin 25
Pub 408/2020 IE–Change 2 (Sec 413)	PG 58S-28	Asphalt binder	215 °F	230 °F	310 °F
	PG 64S-22	Asphalt binder	220 °F	240 °F	320 °F
	PG 64E-22	Asphalt binder	240 °F	260 °F	330 °F
	All other binders	Asphalt binder	The higher of 215 °F or the minimum temp. specified in Bulletin 25 minus 45	The higher of 230 °F or the minimum temp. specified in Bulletin 25 minus 30	Specified in Bulletin 25

RAP/RAS

There have been no changes in RAP/RAS requirements since Pub 408/2016-IE. As Section 409 and 411 were removed, the specifications for RAP/RAS were moved to Section 413, which is the newly added section of Pub 408/2020-IE. The terms of HMA and WMA were changed to asphalt mixtures.

As specified in PennDOT Pub 408, RAP/RAS is allowed in asphalt mixtures and currently a two-tier approach is followed: (1) 5–15% RAP, or 5% RAS and (2) more than 15% RAP, or 5% RAS with more than 5% RAP. The ratio of RAP/RAS is based on mass of the total asphalt mixture. PennDOT is moving toward a tiered approach based on reclaimed binder ratio rather than the RAP/RAS content. This is also the case with many other states.

Tack coat

It was mentioned that a major improvement was made to Tack Specification (Section 460) of PennDOT Pub 408 as reflected in 2016 IE–2016 Change 2. The application rate for emulsified asphalt tack coat was set in the range of 0.02–0.07 gal/yd^2. In PennDOT Pub 408/2016-3, use of AET, which has a high water content, was removed to allow a faster curing rate. Furthermore, a non-tracking tack coat specification has been added with additional changes to update application rates to account for variable surface textures that are encountered in the field. The application temperature for Tack and NTT/CNTT are 90–150 °F and 140–180 °F, respectively. The uniform asphalt residual rates by surface type are 0.03–0.05 gal/yd^2 for new asphalt paving, 0.04–0.07 gal/yd^2 for existing asphalt paving, and 0.04–0.08 gal/yd^2 for milled surface.

4.4 Chapter Summary

In this chapter, the Penn State research team investigated the limitations and concerns – related to design and construction of concrete sidewalks and asphalt pavements – that have been identified by PennDOT since publication of its Construction Specifications, Publication 408/2016-IE. This was done by a review of relevant PennDOT specification changes as well as strike-off letters since the release of the 408/2016-IE document.

Based on the above review, it was observed that, in recent years, PennDOT has significantly improved and tightened its specifications for concrete pavements. This includes raising the quality requirements for Class AA concrete (for pavements) by reducing the maximum allowable w/cm and increasing the minimum required 28-day compressive strength. PennDOT has also expanded the requirements for construction and curing of concrete pavements, including limiting the allowable water evaporation rate during construction and disallowing the use of steel or Fresno floats or adding water or monomolecular film to the concrete surface to assist in finishing.

Based on the above review as well as the conclusions of Chapters 2 and 3, the authors recommend that PennDOT designate the use of Class AA (form paving) concrete for construction of sidewalks and adopt the above requirements for finishing and curing of concrete sidewalks. Additionally, it is advisable to provide guidance or mandate to contractors for limiting the maximum slump and maximum SCM content of concrete mixtures and for developing plans to mitigate set retardation and to ensure proper construction and curing of SCM-rich concrete mixtures.

PennDOT specifications related to asphalt pavements have also been improved significantly within the last 5 years. Some of these improvements include mandatory use of anti-stripping agents, use of fine Superpave asphalt mixtures for thin asphalt paving, type of materials used for tack coat, and tack coat application rates. There were also major changes in weather and seasonal limitations of asphalt paving, relating the extension to the type of asphalt mix, and including a spring evaluation of the pavement by the Department. In the path forward, and as discussed in Chapter 3, the authors recommend that PennDOT utilize a thermal imaging system during extended season and cold weather paving. It is also recommended that future specifications include balanced mix design, BMD, and performance testing as part of mix design and even production quality control. Finally, PennDOT Bulletin 27 (Asphalt Mixtures Design Procedures and Specifications) has not kept pace with the changes in construction specifications. While the strike-off letters have been the key documents in improving the asphalt mix design procedures and protocols, revisions have not been reflected in Bulletin 27, and the last official change in the bulletin goes back to January 2011.

Chapter 5. Review of the Approved Concrete and Asphalt Materials in District 4

5.1 Introduction

This chapter provides a review of the approved materials and additives used in concrete and asphalt projects in PennDOT District 4 and evaluates whether all such approved sources can lead to producing high-quality concrete and asphalt mixtures. This review includes:

- All approved aggregate sources within District 4 for concrete and asphalt projects, as included in PennDOT Bulletin 14;
- All approved and provisionally approved materials that are included in PennDOT Bulletin 15 for use in concrete and asphalt projects in District 4, including portland cements, SCMs, admixtures and chemicals, and bituminous materials and additives;
- Locally (project specific) approved materials within District 4 that are not included in Bulletin 14 or 15; and
- Approved producers of bituminous materials (Bulletin 41) and ready-mix concrete (Bulletin 42) that serve projects within District 4.

By searching Bulletin 14, it was determined that while some aggregate sources can be retrieved by restricting the ECAMMS search to District 4, there are other aggregate sources that are geographically located within District 4 or its neighboring counties that are not retrieved by such search. As such, and to make sure all materials and additives that are commonly used in concrete and asphalt projects within District 4 are subject to review in this chapter, the Penn State team considered the entire ECAMMS data under Bulletins 14, 15, 41, and 42, and came up with its own criteria to filter the data and identify materials that are likely to be used within District 4 projects. As such, the criteria provided in **Table 54** were selected to identify the materials that are physically sourced within District 4 or its neighboring counties.

Table 54. Criteria used to identify the approved materials within District 4

Material (Pub 408 Section)	**Bulletin**	**Criteria**	**Number of materials meeting the criteria**
Coarse aggregates (Sec 703)	Bulletin 14	Within 70 miles from Wilkes-Barre, PA	101 for concrete 57 for asphalt
Fine aggregates (Sec 703)	Bulletin 14	Within 70 miles from Wilkes-Barre, PA	22 for concrete 70 for asphalt
Portland cements (Sec 701)	Bulletin 15	Within 100 miles from Wilkes-Barre, PA	43
SCMs (Sec 724)	Bulletin 15	Entire Bulletin 15	67
Admixtures and chemicals (Sec 503, 711)	Bulletin 15	Entire Bulletin 15	557
Ready-mix concrete suppliers	Bulletin 42	Within 100 miles from Wilkes-Barre, PA	68
Bituminous materials and additives (Sec 411, 470, 702, MISC)	Bulletin 15	Within 100 miles from Wilkes-Barre, PA	439
Locally approved materials	According to the email from Mr. Robert McGowan dated 5/19/21, no non-bulletin materials have been used in District 4 projects over the past 5 years		0
Producers of bituminous mixtures	Bulletin 41	Within 100 miles from Wilkes-Barre, PA	72

5.2 Concrete Materials and Additives

<u>Aggregates (Bulletin 14)</u>

Bulletin 14 provides a list of all aggregate sources that have been approved by PennDOT for various applications, including those used for concrete and asphalt mixtures. After applying the criteria in **Table 54**, 101 coarse aggregates and 22 fine aggregates were identified as approved for use within District 4 for cement concrete applications. Aggregates listed under Bulletin 14 have been demonstrated to meet PennDOT's specification requirements for the type and source listed. The approval procedure for aggregates is described within the Supporting Information section of Bulletin 14 [108] and involves:

- Preliminary approval procedure
  - Prospective aggregate producers must request an investigation of their materials from the District Materials Engineer/Manager (DME/DMM), who is responsible for the source location (e.g., District 4). All information related to the exploratory work and aggregate property test results conducted by an independent testing agency must be provided to demonstrate whether the quality of aggregates meets the requirements specified in Publication 408 Section 703 (**Table 55**). The DME/DMM reviews the results and continues the investigation if it is merited.
  - Facilities and equipment (e.g., mechanical sieve shakers with timers) must be properly in place before receiving the recommendation from the DME/DMM. They must be properly maintained to continue the listing of the source in Bulletin 14. Routine maintenance and repair of all equipment are required.

- Quality control (QC) procedure
  - To ensure that an aggregate source maintains adequate quality over time, annual QC tests must be performed by the producer or an independent laboratory and the results reported to the DME/DMM and to PennDOT's Laboratory Testing Section

(LTS) in Harrisburg, PA. For coarse aggregates, annual QC tests include the following: specific gravity and absorption, sodium sulfate soundness, Los Angeles abrasion, crushed fragments, bulk density (unit weight), mass % of thin and elongated particles, and petrographic analysis. For fine aggregates, the annual QC tests include the following: specific gravity and absorption, sodium sulfate soundness, uncompacted voids, bulk density (unit weight), petrographic analysis, strength ratio, and sand equivalency. Also, a QC plan must be prepared and submitted to DME/DMM for the initial source approval and annually thereafter to ensure compliance of the source with the specification requirements.

- Additionally, various sample types are defined under Bulletin 14 for use in the QC process to be provided by the supplier to PennDOT's LTS for testing. These include preliminary samples (Class PS), qualification samples (Class QS), requalification samples (Class RS), quality assurance samples (Class QA), and independent assurance samples (Class IA). All PS, QS, and RS samples are tested by LTS based on the samples provided by the supplier. The furnished sample size, which includes the number of sample increments (i.e., bags) and the quantity of material in each bag, is dependent on the type of aggregate (fine or coarse), aggregate quality, sample classification, and aggregate size (e.g., AASHTO #57).

Table 55. Quality parameters for coarse and fine aggregates as required in PennDOT Publication 408/2020-2

Quality parameters	Test method	Coarse agg.		Fine agg.	
		Cement concrete	**Bituminous concrete**	**Cement concrete**	**Bituminous concrete**
Gradation*	Pub 408/2020-2 & Bulletin 27 2A	Required	Required (Combined agg. - Bulletin 27 2A)	Required	Required (Combined agg. - Bulletin 27 2A)
Bulk density (unit weight)*	AASHTO T 19 [109]	Required per Bulletin 14 Supplemental Info			
Specific gravity and absorption	AASHTO T 85 [110] & AASHTO T 84 [111]	Required			
Sodium sulfate soundness	PTM No. 510 [112]	Required			
Uncompacted voids	AASHTO T 304 [113]	-	-	Required per Bulletin 14 Supplemental Info	
Sand equivalency	AASHTO T 176 [114]	-	-	-	Required
Strength ratio*	AASHTO T 21M [115]	-	-	Required	-
Material finer than the 75 µm sieve*	PTM No. 100 [116]	-	-	Required	-
Fineness modulus*	PTM No. 501 [117]	-	-	Required	-
Los Angeles abrasion	AASHTO T 96 [118]	Required		-	-
Micro-Deval loss	AASHTO T 327 [119]	Not required but provided in Bulletin 14		-	-
% Thin and elongated pieces	ASTM D4791 [120]	Required		-	-
Crushed fragments (% 1-face and % 2-face)	ASTM D5821 [121]	Required		-	-
Alkali-Silica Reactivity (ASR)	ASTM C1293 [42]	Required	-	-	-
Rock composition and order of abundance	Petrographic analysis PTM No. 518 [122]	Required per Bulletin 14 Supplemental Info			
Skid Resistance Level (SRL)	Bulletin 14 [108]	Provided in Bulletin 14 based on petrographic analysis		-	-
Deleterious shale*	PTM No. 519 [123]	Required		-	-
Clay lumps*	Visual identification	Required		-	-
Friable particles*	PTM No. 620 [124]	Required		-	-
Coal or coke*	Visual identification	Required		-	-
Glassy particles*	Visual identification	Required		-	-
Metallic iron*	PTM No. 518 [122]	Required		-	-

* Not reported in Bulletin 14

- Final approval procedure
    - The final approval of a source will be granted if all aggregate test results meet the specification's requirements and if all facilities, equipment, and plants are properly in place as required.

Table 55 summarizes the aggregate material properties that are required according to PennDOT Publication 408 Sec. 703 or per Bulletin 14 Supplemental Information [1]. While this information is used for approval and QC procedures of aggregate sources, not all such information is publicly available under Bulletin 14. And even for those properties that are reported in Bulletin 14, not all aggregate sources identified in District 4 have reported values for all such properties. For example, from the 101 cement concrete coarse aggregates (A57 and A8) identified in District 4, only 74 have reported ASR results, 98 have Micro-Deval results, 90 have SRL rating, and 98 have reported mass % thin and elongated particles.

For use in cement concrete mixtures, Type A fine aggregates meeting the requirements provided in **Table 56** must be used. This table provides a side-by-side comparison of PennDOT Publication 408 requirements, ASTM C33/C33M–18 "Standard Specification for Concrete Aggregates" [125], and AASHTO M 6-13 (2018) "Standard Specification for Fine Aggregate for Hydraulic Cement Concrete" [126]. The ASTM and AASHTO requirements are nearly identical. The PennDOT requirements are also quite similar except for small differences in the gradation. PennDOT evaluates the effect of presence of organic impurities within fine aggregates using AASHTO T 21M/T 21-20 "Standard Method of Test for Organic Impurities in Fine Aggregates for Concrete" [115] while ASTM C33 and AASHTO M 6 [126] have criteria for max % of coal and lignite as well as max % for clay lumps and friable particles.

Figure 17 provides histograms summarizing the properties of the 22 fine aggregates from District 4. A comparison with the requirements of **Table 56** suggests that all such 22 fine aggregates meet the PennDOT, ASTM, and AASHTO specification requirements based on the information provided under Bulletin 14. As such, these aggregates can be used for production of high-quality concrete. It is important to note that not all required information is publicly available under Bulletin 14; for example, information regarding fine aggregate gradation, strength ratio, and fineness modulus are not reported. However, since the 22 District 4 sources have been approved as Type A fine aggregates for use in cement concrete, it is assumed that all such aggregates meet PennDOT's requirements listed in **Table 56**.

The alkali silica reactivity of both coarse and fine aggregates is measured based on ASTM C1293 test [42]. According to **Figure 17(d)**, out of the 22 fine aggregates in District 4, 17 are non-reactive (Class R0), 4 are moderately reactive (Class R1), and 1 is not reported. For all aggregates within class R1, ASR mitigation measures such as using SCMs must be employed according to Section 704.1(g) of Publication 408.

Table 56. Fine aggregates gradation (% passing) and quality requirements for use in cement concrete pavements and sidewalks

Sieve Size	Type A sand Pub. 408/2020-2, Sec. 703.1(c)	ASTM C33/C33M–18	AASHTO M 6-13 (2018)	Number of District 4 fine aggregate sources meeting the criteria	Range of reported data in Bulletin 14
9.5 mm (3/8-inch)	100	100	100	Not reported	Not reported
4.75 mm (No. 4)	95–100	95–100	95–100		
2.36 mm (No. 8)	70–100	80–100	80–100		
1.18 mm (No. 16)	45–85	50–85	50–85		
600 µm (No. 30)	25–65	25–60	25–60		
300 µm (No. 50)	10–30	5–30	5–30		
150 µm (No. 100)	0–10	0–10	0–10		
75 µm (No. 200)	-	0–3	-		
Material finer than 75 µm (Max%)	3	3	2.0 to 5.0**		
Strength ratio (Min %)	95	-	-	Not reported	Not reported
Sodium sulfate soundness (Max loss %)	10	10	10	22	2–8%
Fineness modulus	2.30–3.15	2.3–3.1	2.3–3.1	Not reported	Not reported
Clay lumps and friable particles (Max %)	-	3.0	3.0	Not reported	Not reported
Coal and lignite (Max %)	-	0.5 or 1.0*	0.25 or 1.0	Not reported	Not reported
Bulk specific gravity	Report only	-	-	22	2.513–2.749
Absorption	Report only	-	-	22	0.6–3.5%
ASR, ASTM C1293	Report and mitigate	Report and mitigate	-	21 (not reported for 1 source)	0.01–0.075%
Uncompacted void content	Report only	-	-	22	43–49%

* 0.5 is for where surface appearance of concrete is important and 1.0 is for all other concrete.
** Depending on whether concrete is subject to surface abrasion.

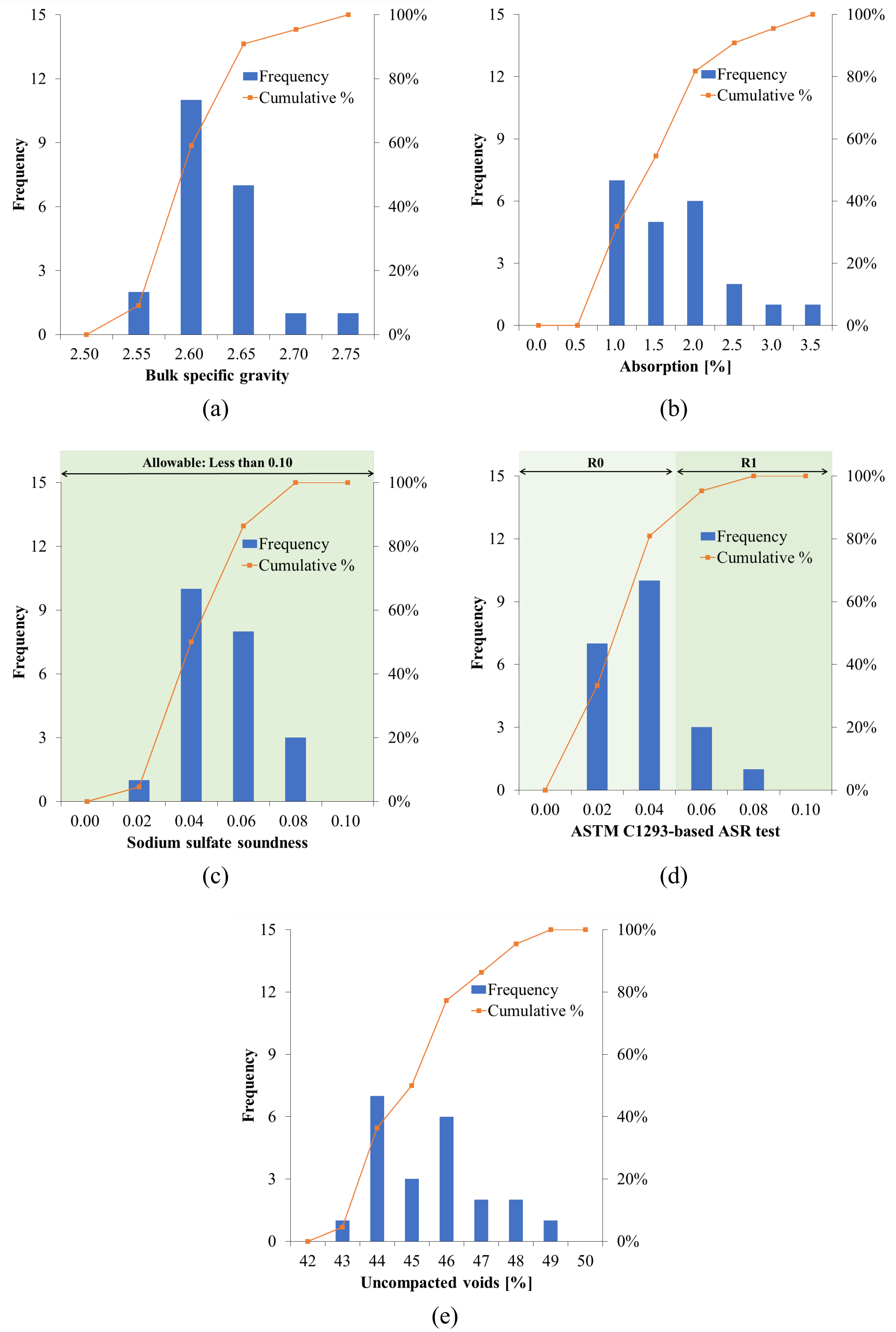


Figure 17. Bulletin 14 information for fine aggregates in District 4: (a) bulk specific gravity, (b) absorption, (c) soundness, (d) ASR, and (e) uncompacted voids

For use in cement concrete mixtures, Type A coarse aggregates with AASHTO gradation #467, #57, #67, or #8 are permissible according to Section 704 of Publication 408. Such coarse aggregates must also meet the requirements provided in **Table 57**. This table provides a side-by-side comparison of PennDOT Publication 408 requirements, ASTM C33/C33M–18 [125], and AASHTO M 80-13 (2017) "Standard Specification for Coarse Aggregate for Hydraulic Cement Concrete" [127]. The ASTM and AASHTO requirements are nearly identical except that the soundness test is performed using magnesium sulfate in ASTM and using sodium sulfate in AASHTO. The PennDOT specification covers the AASHTO M 80 [127] requirements and adds several additional criteria; for example, on max % of thin and elongated particles and min % of crushed fragments.

While the values of many aggregate properties (e.g., % crushed fragments, bulk density, etc.) are not reported in **Table 57**, based on the available information, all 101 identified coarse aggregate sources in District 4 meet specification requirements set by PennDOT, ASTM, and AASHTO to produce high-quality concrete. The available information is also presented in the form of histograms in **Figure 18** and **Figure 19**.

As mentioned earlier, the ASR reactivity of both coarse and fine aggregates is measured based on ASTM C1293 test [42]. According to the histogram in **Figure 18(d)**, out of the 101 coarse aggregates in District 4, 14 are non-reactive (Class R0), 28 are moderately reactive (Class R1), 30 are highly reactive (Class R2), and 2 are very highly reactive (Class R3). The ASR results for 27 coarse aggregates are not provided in Bulletin 14. For all aggregates within classes R1, R2, and R3, ASR mitigation measures such as use of SCMs must be taken according to Section 704.1(g) of Publication 408.

Table 57. Coarse aggregates quality requirements for use in cement concrete pavements and sidewalks

<table>
<tr><th>Sieve Size</th><th>Type A coarse agg. Pub. 408/2020-2, Sec. 703.1(c)</th><th>ASTM C33/C33M–18</th><th>AASHTO M 80-13 (2017)</th><th>Number of District 4 fine aggregate sources meeting the criteria</th><th>Range of reported data in Bulletin 14</th></tr>
<tr><td>Sodium sulfate soundness (Max loss %)</td><td>10</td><td>-</td><td>12</td><td>101</td><td>0–7%</td></tr>
<tr><td>Magnesium sulfate soundness (Max loss %)</td><td>-</td><td>18</td><td>-</td><td>Not reported</td><td>Not reported</td></tr>
<tr><td>Material finer than 75 µm (Max %)</td><td>1</td><td>1.0</td><td>1.0</td><td>Not reported</td><td>Not reported</td></tr>
<tr><td>LA abrasion loss (Max %)</td><td>45</td><td>50</td><td>50</td><td>101</td><td>12–39%</td></tr>
<tr><td>Thin and elongated particles (Max %)</td><td>15</td><td>-</td><td>-</td><td>98 (not reported for the other 3 sources)</td><td>0–9%</td></tr>
<tr><td>Crushed fragments (Min %)</td><td>55</td><td>-</td><td>-</td><td rowspan="12">Not reported</td><td rowspan="12">Not reported</td></tr>
<tr><td>Bulk density (unit weight) lb/ft^3</td><td>70</td><td>-</td><td>-</td></tr>
<tr><td>Clay lumps and friable particles (Max %)</td><td>-</td><td>3.0</td><td>3.0</td></tr>
<tr><td>Chert (less than 2.40 Sp Gr SSD) (Max %)</td><td>-</td><td>5.0</td><td>3.0</td></tr>
<tr><td>Sum of clay lumps, friable particles, and chert (Max %)</td><td>-</td><td>5.0</td><td>5.0</td></tr>
<tr><td>Coal and lignite (Max %)</td><td>1</td><td>0.5</td><td>0.5</td></tr>
<tr><td>Deleterious shale (Max %)</td><td>2</td><td>-</td><td>-</td></tr>
<tr><td>Clay lumps (Max %)</td><td>0.25</td><td>-</td><td>-</td></tr>
<tr><td>Friable particles excl. shale (Max %)</td><td>1.0</td><td>-</td><td>-</td></tr>
<tr><td>Glassy particles (Max %)</td><td>4</td><td>-</td><td>-</td></tr>
<tr><td>Iron (Max %)</td><td>3</td><td>-</td><td>-</td></tr>
<tr><td>Sum of deleterious shale, clay lumps, friable particles, and coal (Max %)</td><td>2</td><td>-</td><td>-</td></tr>
<tr><td>Bulk specific gravity</td><td>Report only</td><td>-</td><td>-</td><td>101</td><td>2.554–2.922</td></tr>
<tr><td>Absorption (Max %)</td><td>3.0</td><td>-</td><td>-</td><td>101</td><td>0.3–2.7%</td></tr>
<tr><td>ASR, ASTM C1293</td><td>Report and mitigate</td><td>Report and mitigate</td><td>Report and mitigate</td><td>74 (not reported for the other 27 sources)</td><td>0.03–0.25</td></tr>
<tr><td>Micro-Deval loss</td><td>-</td><td>-</td><td>-</td><td>98 (not reported for the other 3 sources)</td><td>4–36%</td></tr>
</table>

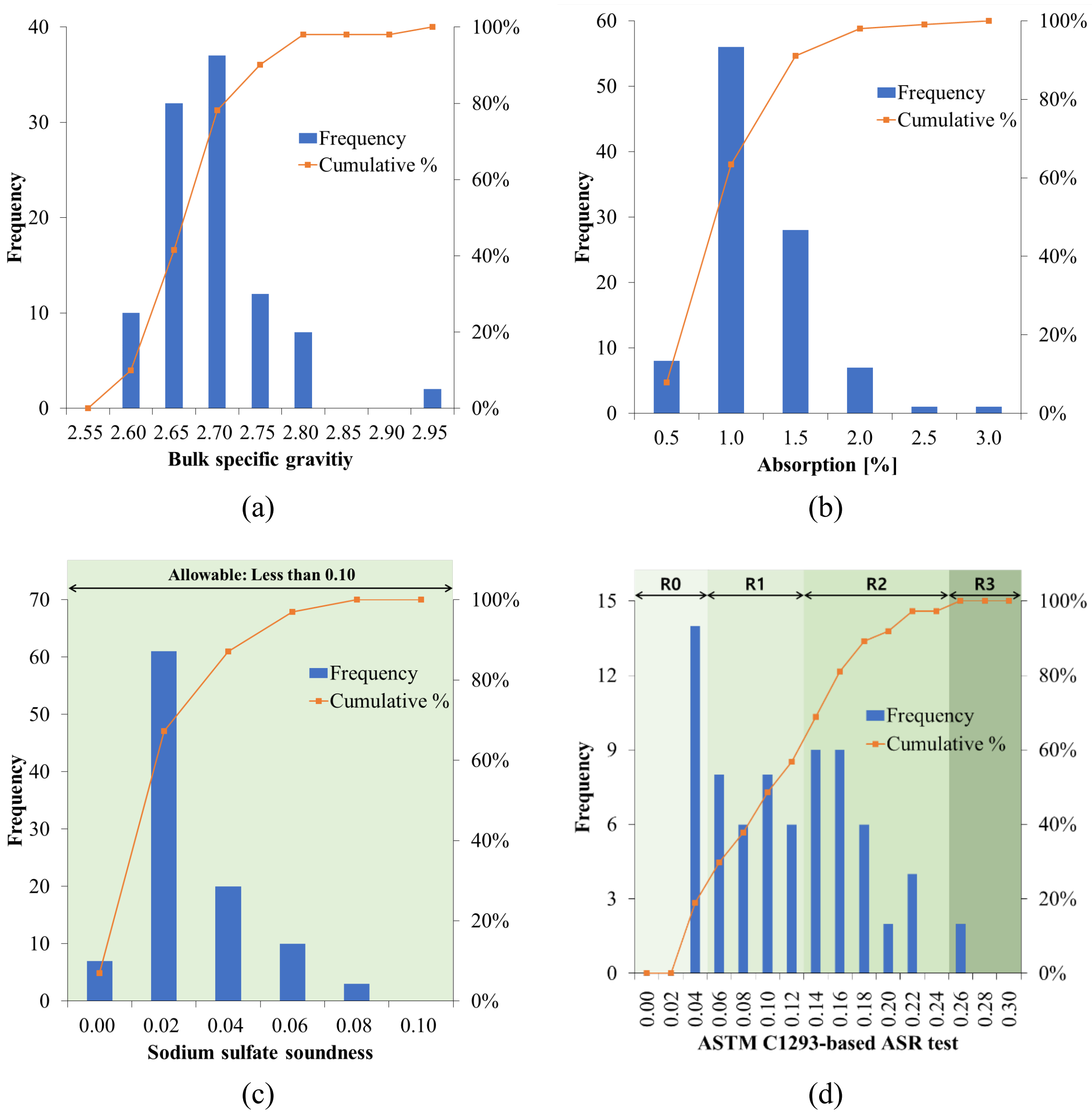


Figure 18. Bulletin 14 information for coarse aggregates in District 4:
(a) bulk specific gravity, (b) absorption, (c) sodium sulfate soundness, (d) ASR expansion

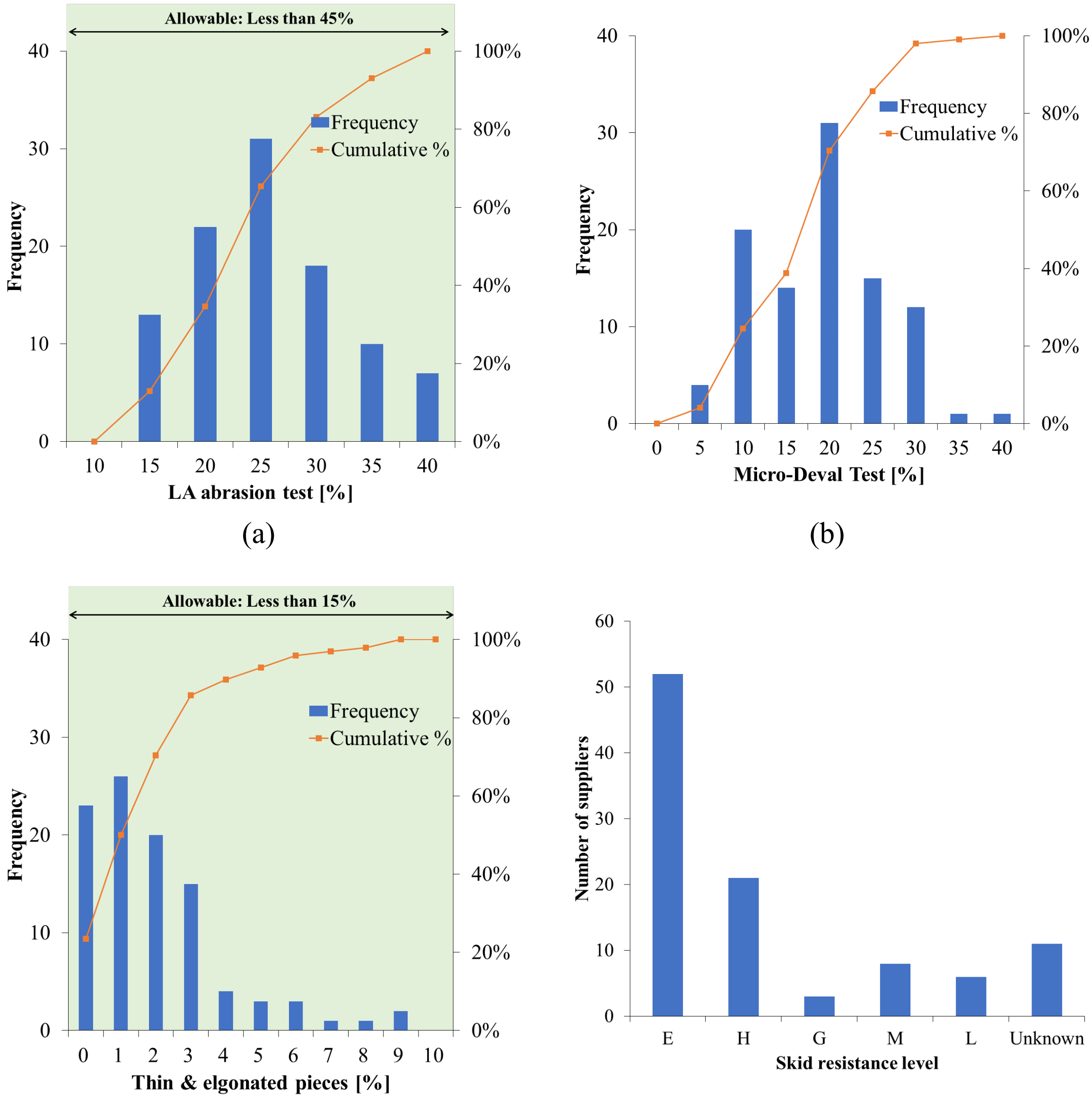


Figure 19. Bulletin 14 information for coarse aggregates in District 4:
(a) LA abrasion, (b) Micro-Deval, (c) mass% thin & elongated, and
(d) skid resistance level

<u>Cements, SCMs, Admixtures, and Chemicals (Bulletin 15)</u>

Bulletin 15 is a listing of prequalified materials that are eligible for use on PennDOT construction projects. For cement concrete projects, these include portland cements, SCMs, and admixtures and chemicals. The purpose of Bulletin 15 is to provide contractors, consultants, PennDOT personnel, manufacturers, suppliers, and others with easy access to a listing of products whose manufacturers have demonstrated the capability to perform in accordance with PennDOT specifications and to be accepted by certification on PennDOT construction projects. Each of the materials within Bulletin 15 has an assigned supplier code, supplier name and address, the product name/type/use, and a reference number.

Materials listed in Bulletin 15 are approved for use only in their intended applications. Producers will be assigned a level of certification, based on their ability to comply with the governing material specifications. Producers are initially assigned a Level 1 Certification. Poor material performance or material quality issues may dictate a re-evaluation of a producer's certification level. Information regarding Levels 1 to 3 Standard Certifications are provided in Bulletin 15 Supporting Information [128] as summarized below.

- Level 1 (Standard Certification)
  This is the initial level of certification, which is typically issued to Bulletin 15 listed producers. The material is produced and tested according to the producer's approved QC plan and there are no performance or quality issues that suggest a reduced level of certification.

- Level 2 (Standard Certification – Reduced)
  Level 2 is the reduced level certification and is issued to a Bulletin 15 listed producer if there are minor/moderate material performance or quality issues. The producer must work with PennDOT to submit an improvement plan that may include a revised QC plan, a failure analysis/action plan to assess why failures are occurring and how to prevent them, and correlation testing between in-house and independent lab testing. The material is then produced and tested according to this improvement plan that has been approved by PennDOT.

- Level 3 (Lot Approval Certification)
  Level 3 is issued to a Bulletin 15 listed producer if a material has exhibited major performance or quality issues. As with Level 2, the producer must work with PennDOT to develop an improvement plan for its material. Any material lot to be used on a project must first be tested and approved via an independent in-plant acceptance testing (IPAT) as meeting the required PennDOT specification prior to shipment to the project. The IPAT testing is conducted side-by-side with "in-house" producer testing at the designated frequencies stated in the revised QC plan. The results from the "in-house" producer testing and the IPAT testing must be correlated and submitted to LTS on a monthly basis.

For the plant verification, producers and manufacturers are required to submit plant verification samples to PennDOT. Producers are advised to keep a sufficient quantity of material from each production lot or batch to serve as retain samples to perform additional testing as requested or directed by PennDOT.

A manufacturer and/or product(s) may be removed from Bulletin 15 for a number of reasons, such as any action or inaction that may affect the quality of the product, the integrity of the test results, or the implementation of the QC plan; failure of the product to meet appropriate specifications; failure to submit or adhere to a QC plan; and falsification of information provided on the Certificate of Compliance Form. A full list of removal reasons is included in Bulletin 15 Supplemental Information.

<u>*Portland cements:*</u> A total of 43 portland cement sources were identified to be associated with District 4 projects based on the criteria of being located within 100 miles of Wilkes-Barre, PA. These all have Level 1 Certification. This includes 17 type I cements, 12 type II cements, 8 type III cements, and 6 blended cements (**Figure 20**). According to Publication 408/2020-2, Section 701, portland cement must meet the requirements of ASTM C150 "Standard Specification for Portland Cement" [129] or ASTM C595 "Standard Specification for Blended Hydraulic Cements" [93]. A monthly mill test must be submitted to LTS for verification of compliance with PennDOT specifications. These ASTM standards are considered as the state-

of-the-art in cement specification. As such, the 43 sources of portland cement are considered to be of the quality required to produce high-quality concrete. It should be noted that ASTM specifications are updated frequently. As such, it is important to ensure compliance with the latest version of each specification. For example, the latest versions of the above ASTM documents are ASTM C150/C150M-20 [129] and ASTM C595/C595M-20 [93]. It is suggested to cite these documents, including their publication year, within Section 701 of Publication 408.

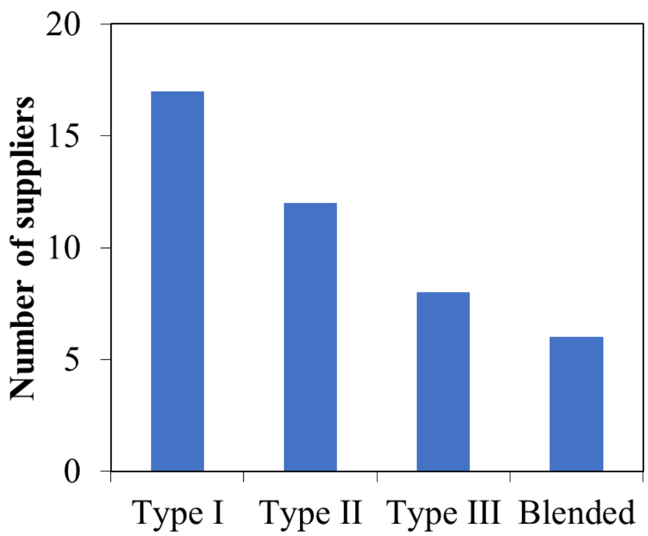


Figure 20. Number and type of available portland cements in District 4 according to Bulletin 15

<u>SCMs:</u> According to Section 724 of Publication 408, SCMs for use in cement concrete include fly ash, slag cement, silica fume, and mechanically modified SCM-cement combinations. Supply sources desiring approval must write the LTS, stating their present QC program, as specified in Section 106.03(a)2 of Pub 408. Fly ash must comply with the requirements of AASHTO M 295, Class C, F, or N, except that the Loss on Ignition has a maximum limit of 6.0% [130]. Class N refers to raw or calcined natural pozzolans such as volcanic ash and calcined clay. As such the use of such pozzolans is implicitly permissible. Also, Section 704.1(g) recognizes metakaolin (calcined clay) as an acceptable SCM type for ASR mitigation.

Slag cement must comply with the requirements of AASHTO M 302, Grade 100 or 120 [131]. Silica fume must comply with the requirements of AASHTO M 307 [132]A. Mechanically modified SCM-cement combinations refer to interground SCM-cement blends containing a minimum of 90% SCM by weight and is intended to replace 50% of cement by weight in cement concrete mixtures as specified in Section 704.1(b). These must be tested according to the AASHTO standard for the base SCM.

A total of 67 SCM sources are listed in PennDOT Bulletin 15 with Level 1 Certification. This includes 22 Class F fly ashes, 11 Class C fly ashes, 1 Class N natural pozzolan, 8 Grade 120 slag cements, 15 Grade 100 slag cements, and 10 silica fumes (**Figure 21**). The above AASHTO specifications are considered as the state-of-the-art in the concrete industry. As such, the 67 SCM sources are considered to be of the quality required to produce high-quality concrete. As with portland cement specification language, it is suggested to cite the latest version of AASHTO documents, including their publication year, within Section 724 of Publication 408. For example, the latest versions of the above AASHTO documents are AASHTO M 295-19, AASHTO M 302-19, and AASHTO M 307-13 (2017) [130–132].

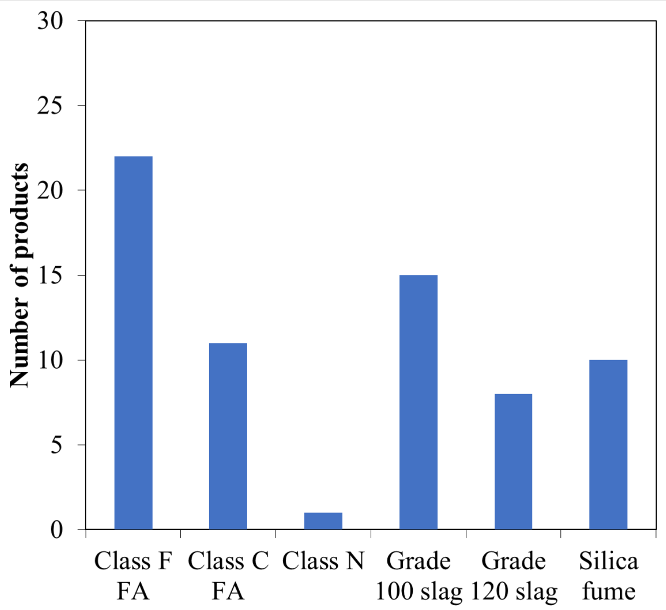


Figure 21. Number and type of available SCMs according to Bulletin 15

Admixtures and chemicals: These include concrete chemical admixtures, curing covers, curing compounds, and protective pavement coating (boiled linseed oil). Out of the 557 materials identified under Bulletin 15, WR are water reducing or high-range water reducing admixtures (Types A, D, E, F, or G according to ASTM C494/C494M-19 [94]), RR are retarding or accelerating admixtures (Types B and C according to ASTM C494 [94]), AA are air-entraining admixtures, SS are specific performance admixtures (e.g., shrinkage reducers, viscosity modifiers, strength-enhancing admixtures, waterproofing admixtures, workability retention admixtures, and others), CP are curing and protective covers, CC are curing compounds, LO are boiled linseed oils, and UN are admixtures and chemicals that are not specified in Bulletin 15 (**Figure 22**).

Curing and protective covers are discussed within Section 711.1 of Publication 408/2020-2. These include white polyethylene sheeting (including burlap-backed and fiber-backed sheets) and must comply with ASTM C171 requirements [133]. Curing and protective covers also include burlap (according to AASHTO M 182, Class 1 [99]); insulating mats (e.g., treated new wood fibers, rock wool, or glass fibers enclosed within weather-proof covers of asphalt-saturated kraft crepe or polyethylene sheeting); and foam insulation (i.e., molded, extruded, or spray-applied polyurethane or molded or extruded polystyrene). Additional requirements on curing and protective covers are specified in section 711.1 of Publication 408.

Curing compounds are discussed within Section 711.2 of Publication 408 and include liquid membrane-forming curing compound, clear or white (according to ASTM C309, Type 1-D [98]); liquid membrane-forming curing compound, white, poly-alpha-methylstyrene (PAMS) (in compliance with ASTM C309, Type 2-B [98]); liquid membrane-forming curing compound, black (emulsified or cut-back asphalt conforming to the requirements of ASTM C309, Type 4); and bridge deck intermediate curing compound (a monomolecular film). Additional requirements on curing compounds are specified in section 711.2. Also, boiled linseed oil (complying with AASHTO M 233 [134]) is discussed in section 503 of Publication 408.

Concrete admixtures are discussed within Section 711.3 of Publication 408 and include water reducing admixtures (Type A), retarding admixtures (Type B), accelerating admixtures (Type C), water reducing and retarding admixtures (Type D), water reducing and accelerating admixtures (Type E), high-range water reducing admixtures (Type F), high-range water reducing and retarding admixtures (Type G), and specific performance admixtures (Type S). All these admixtures must comply with requirements of AASHTO M 194M/M 194-13 (2017) [135]. Additionally, permissible concrete admixtures under Section 711.3 include air-entraining admixtures (complying with AASHTO M 154 [136]), latex emulsion admixture (complying with the report FHWA-RD-78-35), synthetic fibers for mitigation of plastic shrinkage cracking (complying with ASTM C1116, 4.1.3-Type III), and colored or white pigments (complying with ASTM C979 [137]).

Since the above-cited ASTM and AASHTO specifications represent the state-of-the-art in the concrete industry, as long as the admixtures and chemicals listed under Bulletin 15 have been carefully vetted to ensure the above specification requirements, they should facilitate production of concrete with good quality and durability.

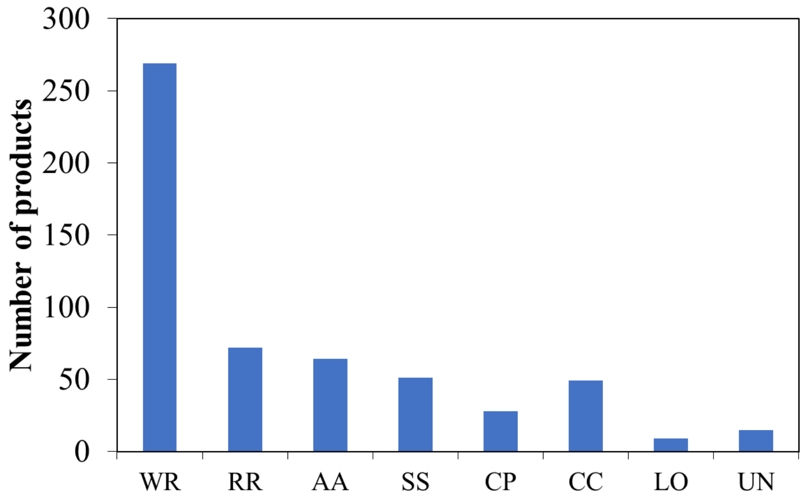


Figure 22. Number and type of available admixtures and chemicals according to Bulletin 15

Producers of ready-mix concrete (Bulletin 42)

The producers listed in Bulletin 42 have demonstrated their capability to comply with PennDOT's specification (Publication 408 Section 704) for the production of ready-mixed concrete as determined by inspection of their plants and facilities. Prospective producers offering a new plant for approval must request plant inspection from the appropriate DME in the District where the plant is located. It is the responsibility of the Bureau of Construction and Materials to approve the listing of ready-mixed plants in Bulletin 42, following the plant inspection and recommendation for approval by the DME. All plants shall be reinspected biennially for compliance and an inspection report shall be submitted by the DME to the Bureau of Construction and Materials, Materials and Testing Division [138].

The approved concrete ready-mix suppliers that are located in District 4 and listed in Bulletin 42 are summarized in **Figure 23**. These include 66 fully automated with recordation plants (Type AO) and 2 automated plants (Type BO). District 4 concrete producers can also be categorized based on their plant sizes and include 3 central mix plants (Type CM), 1 dry batch plant (Type DB), 10 drum mix plants (Type DM), 1 horizontal reversing mix plant (Type RM), 47 transit mix plants (Type TM), and 6 truck mix plants (Type TK).

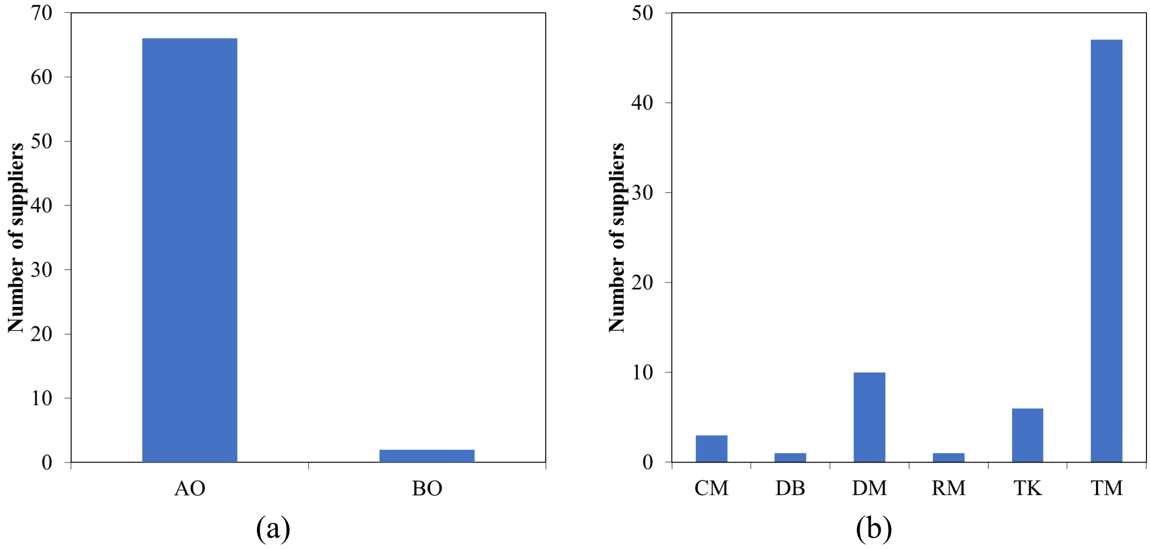


Figure 23. Bulletin 42 – (a) number of concrete suppliers and (b) plant size of suppliers in District 4

5.3 Asphalt Materials and Additives

Aggregates (Bulletin 14)
In the PennDOT Specifications, coarse aggregates for use in asphalt mixes should meet the requirements for Los Angeles abrasion test, morphology (thin and elongated pieces), and amount of crushed fragments, specified in Bulletin 27 2A Table 5A [60] and AASHTO M 323 Table 6 [61] for flat and elongated and fracture faces coarse aggregates, respectively. Testing methods for Los Angeles abrasion (AASHTO T 96 [118]), thin and elongated pieces (ASTM D4791 [120]), and crushed fragments (ASTM D5821 [121]) are also specified in **Table 55**. In Bulletin 14, results of abrasion and thin and elongated pieces are provided. In case of fine aggregate, it should meet the requirements for uncompacted void content and sand equivalency as specified in AASHTO M 323 Table 6 [61]. Testing methods for uncompacted void content and sand equivalency are AASHTO T 304 Method A [113] and AASHTO T 176 [114]. This information is also provided in Bulletin 14.

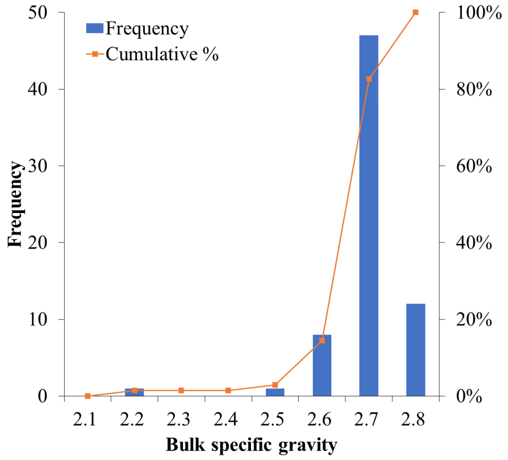
For use in asphalt concrete mixtures, Type B fine aggregates meeting the requirements provided in **Table 58** must be used. This table provides a side-by-side comparison of PennDOT Publication 408 requirements, ASTM D1073–16 "Standard Specification for Fine Aggregate for Asphalt Paving Mixtures" [139], and AASHTO M 323-17 "Standard Specification for Superpave Volumetric Mix Design" [61]. The ASTM requirements are focusing on grading and soundness. The PennDOT grading requirements for Type B #1 and B #3 are corresponded to #1 and #4 in ASTM D1073 [139], respectively. The PennDOT requirement for sodium sulfate soundness is the same as that in ASTM D1073 [139]. PennDOT evaluates the uncompacted void content and sand equivalency using the requirements specified in AASHTO M 323-17 [61].

Figure 24 provides histograms summarizing the properties of the 70 fine aggregates from District 4 for use in asphalt mixes. A comparison with the requirements of **Table 58** suggests that more than 55 fine aggregates meet the PennDOT, ASTM, and AASHTO specification requirements based on the information provided under Bulletin 14. 10 fine aggregates having sand equivalency < 40% do not meet the requirements. Fine aggregates meeting the quality requirements can be used for production of high-quality asphalt concrete. It should be noted that some required information is not available from Bulletin 14.

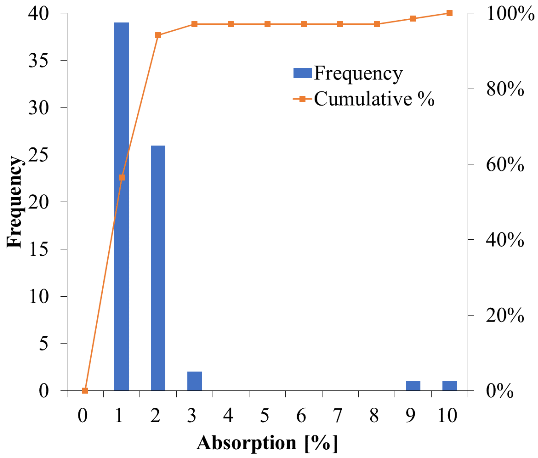
Table 58. Fine aggregates gradation (% passing) and quality requirements for use in asphalt concrete pavements

Sieve Size/ Property	Asphalt concrete sand Pub 408/2020-2 Sec 703.1(c)			AASHTO M 323-17	ASTM D1073-16					Number of District 4 fine aggregate sources meeting the criteria	Range of reported data in Bulletin 14
	Type B #1	Type B #3	Type B filler		#1	#2	#3	#4	#5		
9.5 mm (3/8-inch)	100	100	-	Combined fine and coarse aggregate gradation requirements (revised in Bulletin 27)	100	-	-	100	100	Not reported	Not reported
4.75 mm (No. 4)	95–100	80–100	-		95–100	100	100	80–100	80–100		
2.36 mm (No. 8)	70–100	65–100	-		70–100	75–100	95–100	65–100	65–100		
1.18 mm (No. 16)	40–80	40–80	-		40–80	50–74	85–100	40–80	40–80		
600 µm (No. 30)	20–65	20–65	100		20–65	28–52	65–90	20–65	20–65		
300 µm (No. 50)	7–40	7–40	95–100		7–40	8–30	30–60	7–40	7–46		
150 µm (No. 100)	2–20	2–20	90–100		2–20	0–12	5–25	2–20	2–30		
75 µm (No. 200)	0–10	0–10	70–100		0–10	0–5	0–5	0–10	-		
Material finer than 75 µm	-	-	-	-	-	-	-	-	-		
Strength ratio (Min %)	-	-	-	-	-	-	-	-	-		
Sodium sulfate soundness (Max loss %)	15	15	-	-	15					69 (not reported for 1 source)	1–11%
Magnesium sulfate soundness	-	-	-	-	20					-	-
Fineness modulus	-	-	-	-	-	-	-	-	-	Not reported	Not reported
Clay lumps and friable particles (Max %)	-	-	-	-	-	-	-	-	-		
Coal and lignite (Max %)	-	-	-	-	-	-	-	-	-		
Bulk specific gravity	Report only			-	-	-	-	-	-	69 (not reported for 1 source)	2.117–2.785
Absorption	Report only			-	-	-	-	-	-	69 (not reported for 1 source)	0.2–9.4%
ASR, ASTM C1293	Report only			-	-	-	-	-	-	21 (not reported for 1 source)	0.02–0.25%
Uncompacted void content (Min. %)	40-45**			40-45**	-	-	-	-	-	69 (not reported for 1 source)	44–61%
Sand equivalency (Min.%)	40-50***			40-50***	-	-	-	-	-	67 (not reported for the other 3 sources)	28–98%

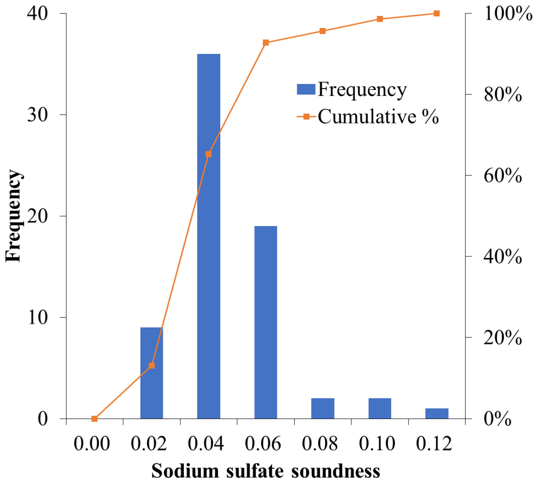
* 0.5 is for where surface appearance of concrete is important and 1.0 is for all other concrete.
** Depending on ESALs and depth from surface. If ESALs is less than 0.3, there is no limits.
*** Depending on ESALs.



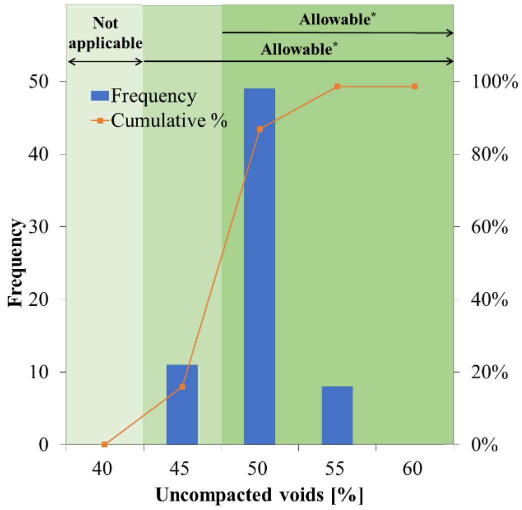
(a)



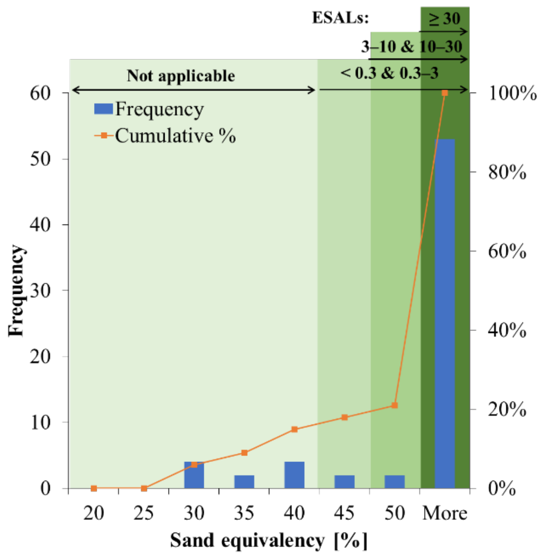
(b)



(c)



(d)



(e)

Figure 24. Bulletin 14 – The properties of fine aggregates in District 4 for use in asphalt mixtures: (a) bulk specific gravity, (b) absorption, (c) sodium sulfate soundness, (d) uncompacted voids, and (e) sand equivalency

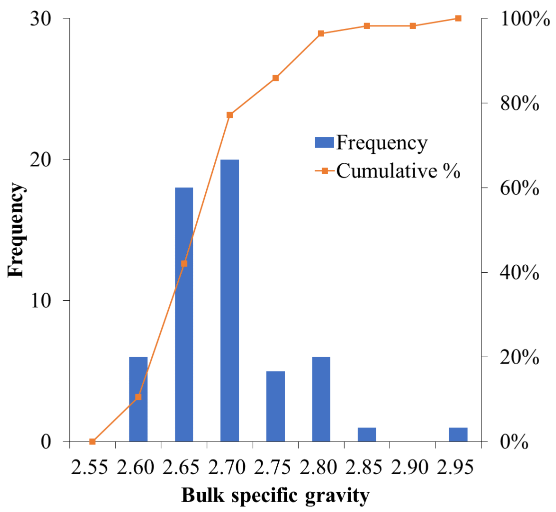
For use in asphalt concrete mixtures, Type A coarse aggregates are permissible in accordance with Section 413 of Publication 408. The size and grading of aggregates (combine coarse and fine aggregates) should meet the requirements in Bulletin 27 2A, which is based on AASHTO M 323 [61]. The quality requirements of such coarse aggregates must meet the specifications provided in **Table 59.** This table provides a side-by-side comparison of PennDOT Publication 408 requirements, AASHTO M 323-17 “Standard Specification for Superpave Volumetric Mix Design” [61], and ASTM D692-20 “Standard Specification for Coarse Aggregate for Asphalt Paving Mixtures” [140]. Quality requirements for LA abrasion, content of thin and elongated particles, and content of crushed fragments in Pub 408/2020 follow the specifications in AASHTO M 323-17 [61]. The ASTM requirements are nearly identical with respect to sodium sulfate soundness and LA abrasion loss.

Even though some aggregate properties, such as bulk density and % of crushed fragments, are not provided in Bulletin 14, all 57 coarse aggregate sources in District 4 meet the requirements (see **Table 59**) for producing high-quality asphalt concrete. The characteristics of available aggregate source in District 4 are presented in the form of histograms of **Figure 25** and **Figure 26**.

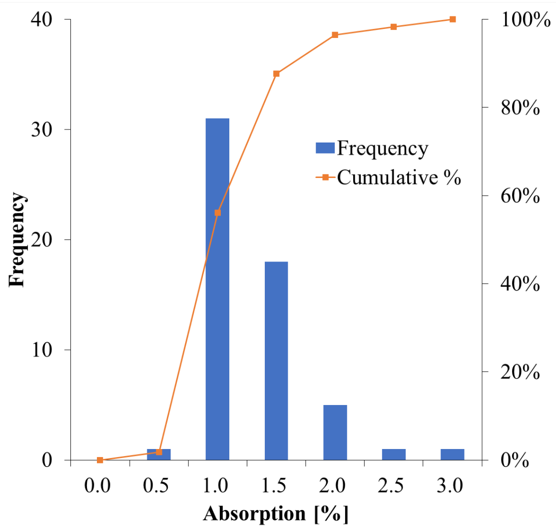
Table 59. Coarse aggregates quality requirements for use in asphalt concrete pavements

Property	Type A coarse aggregate Pub. 408/2020-2, Sec. 703.2	AASHTO M 323-17	ASTM D692-20	Number of District 4 coarse aggregate sources meeting the criteria	Range of reported data in Bulletin 14
Sodium sulfate soundness (Max loss %)	10	-	12	57 (all)	0–9%
Magnesium sulfate soundness (Max loss %)	-	-	18	Not reported	Not reported
Material finer than 75 µm (Max %)	1	-	-	Not reported	Not reported
LA abrasion loss (Max %)	35–40*	35–40*	40 for surface & 50 for base courses	57 (all)	5–39%
Thin and elongated particles (Max %)	10	10	-	55 (not reported for the other 2 sources)	0–9%
Crushed fragments (Min %)	Varied**	Varied**	-	Not reported	Not reported
Bulk density (unit weight) lb/ft^3	70	-	-		
Clay lumps and friable particles (Max %)	-	-	-		
Chert (less than 2.40 Sp Gr SSD) (Max %)	-	-	-		
Sum of clay lumps, friable particles, and chert (Max %)	-	-	-		
Coal and lignite (Max %)	1	-	-		
Deleterious shale (Max %)	2	-	-		
Clay lumps (Max %)	0.25	-	-		
Friable particles excl. shale (Max %)	1.0	-	-		
Glassy particles (Max %)	4	-	-		
Iron (Max %)	3	-	-		
Sum of deleterious shale, clay lumps, friable particles, and coal (Max %)	2	-	-		
Bulk specific gravity	Report only	-	-	57 (all)	2.554–2.912
Absorption (Max %)	3.0	-	-	57 (all)	0.4–2.7%
Micro-Deval loss	-	-	-	55 (not reported for the other 2 sources)	5–33%

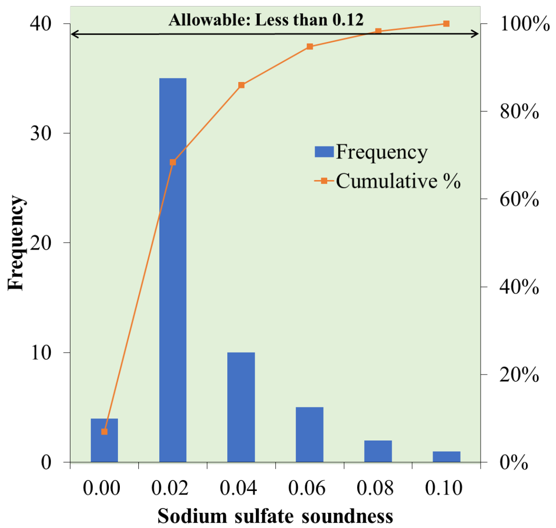
* Depending on ESALs.
** Depending on ESALs and depth from surface. See AASHTO M 323 Table 6



(a)



(b)



(c)

Figure 25. Bulletin 14 – The properties of coarse aggregate sources in District 4 for use in asphalt mixtures: (a) bulk specific gravity, (b) absorption, and (c) sodium sulfate soundness

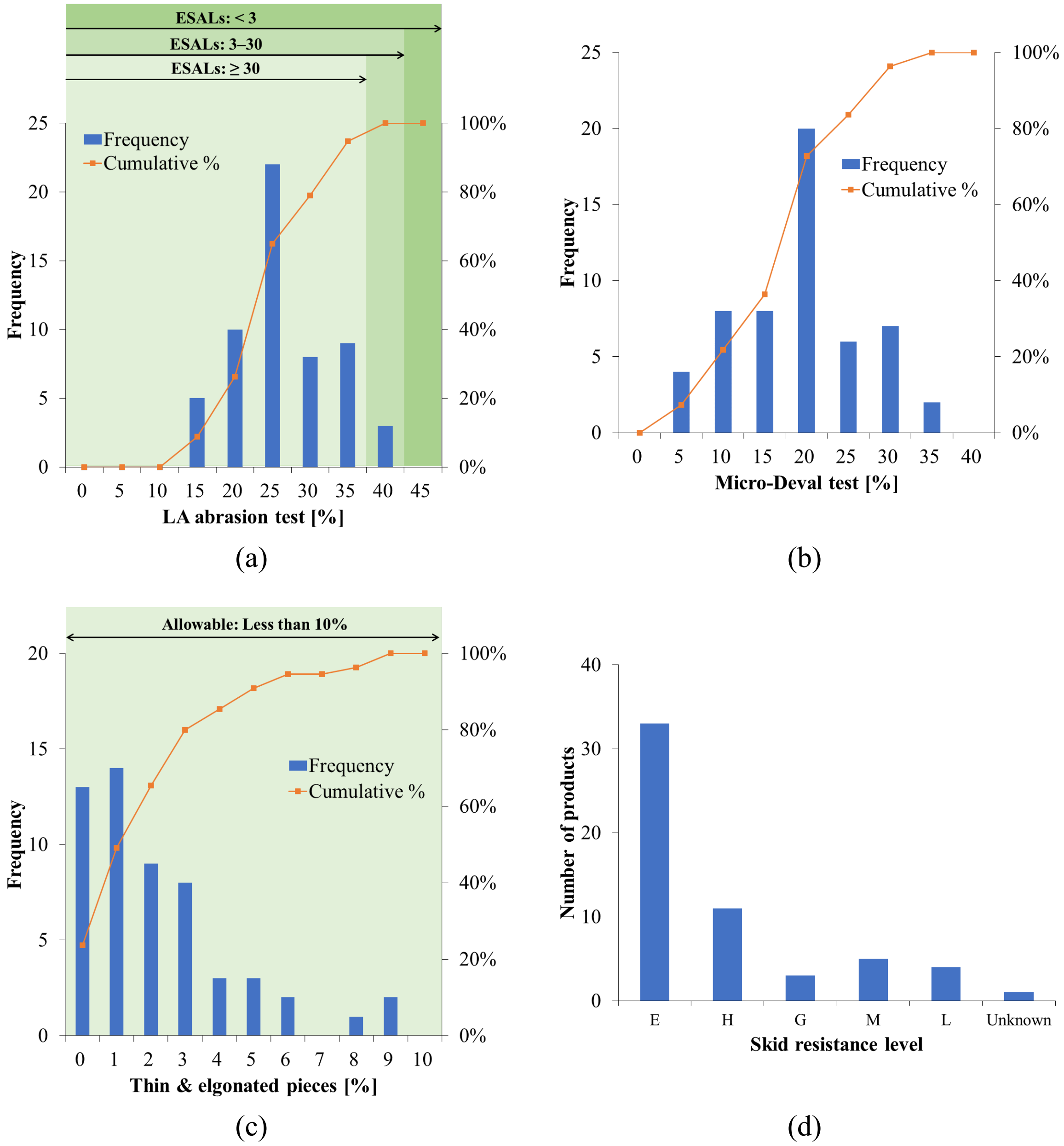


Figure 26. Bulletin 14 - The properties of coarse aggregate sources in District 4 for use in asphalt mixtures: (a) LA abrasion, (b) Micro-Deval test, (c) thin & elongated particles, and (d) skid resistance level

<u>Approved materials related to asphalt pavement construction (Bulletin 15)</u>

There are a large number of approved products that are listed in Bulletin 15 as related to design and construction of asphalt pavements. These includes products such as WMA technologies, rubberized asphalt, antistripping agents, and emulsified asphalt, crumb rubber modifiers, stabilizing fibers. Approved WMA technologies (e.g., additives, modifies, or processes) include chemical additives, foaming additives, mechanical foaming equipment, and organic additives. In addition, the bulletin also lists approved sources for asphalt cement, cut-back asphalt, and performance grade asphalt binder as required in Pub 408 Section 702. **Figure 27** provides the number of asphalt-related approved products within 100 miles of Wilkes University.

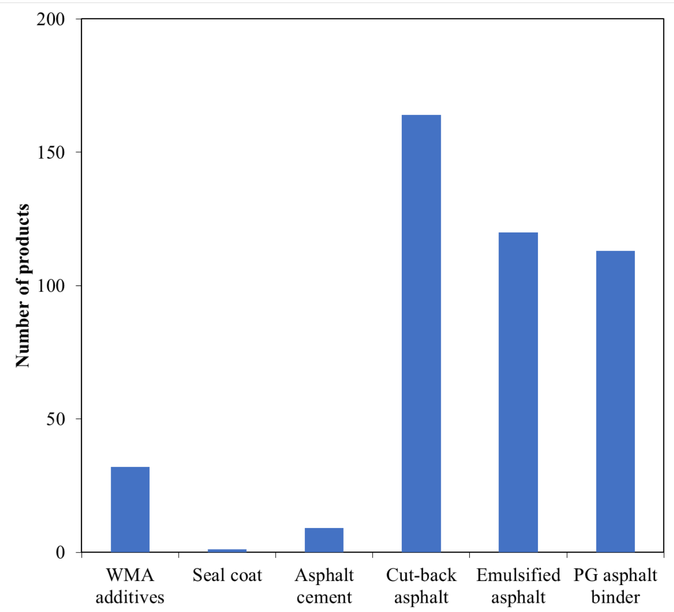
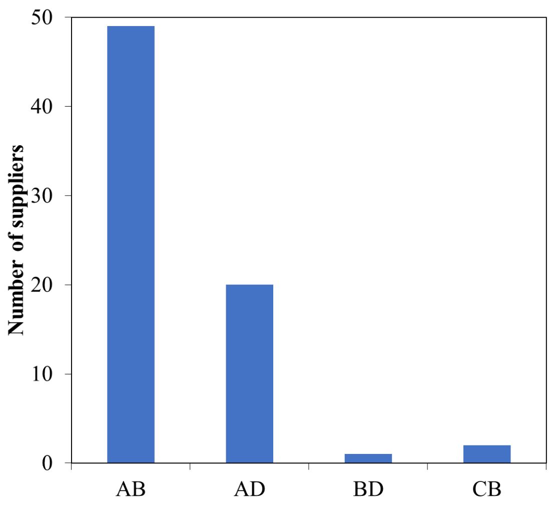


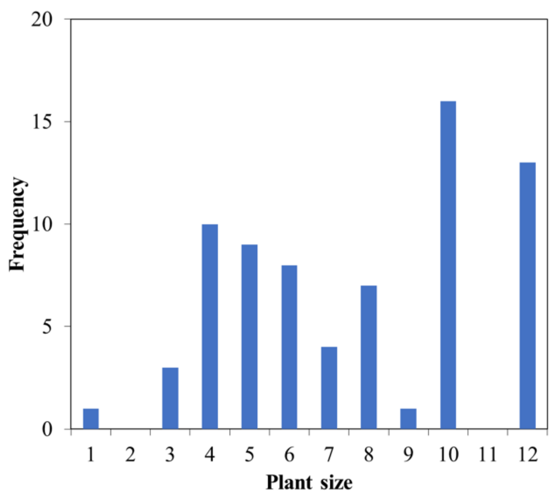
Figure 27. Bulletin 15 - Number of available chemical additives and asphaltic materials in District 4

Bituminous materials (Bulletin 41)

The available bituminous material suppliers in District 4 are summarized in **Figure 28**, which are collected from Bulletin 41. It was found that four types of plants (AB: Fully automated with recordation – batch mixing; AD: Fully automated with recordation – drum mixing; BD: Automated – drum mixing; CB: Manual – batch mixing) are located at District 4. The number of AB plants is 49, which is much higher than other types of plants (20 for AD, 1 for BD, and 2 for CB). Plant sizes are varied from 1 to 12.



(a)



(b)*

*Plant size: Batch plant - Number ks (pounds) × 1,000/Batch (e.g., 1,000 pounds = 01, 35,000 pounds = 35); Continuous or Drum - Number tons × 10/hour (e.g., 100 tons/hour = 01, 750 tons/hour = 08)

Figure 28. Bulletin 41 – (a) number of bituminous material suppliers and (b) plant size of suppliers in District 4

An Overview of Asphalt Additives and Modifiers

Bulletin 15 covers a wide range of additives and modifiers that have been approved to be used in asphalt binder and asphalt concrete. The need to include such additives/modifiers in asphalt is expected to grow with time. We believe the expected increase in the use of asphalt additives with time will be the result of several factors: for one, there is almost a widespread perception that the quality of some binders has deteriorated with time, i.e., some binders are not as good as they used to be. The refineries have become more efficient in extracting more valuable components such as gasoline from crude oil, hurting the quality of material known as the bottom of the barrel (i.e., asphalt). This concern becomes more pronounced when we consider the current trend in the increase of using higher contents of reclaimed asphalt pavement (RAP) or the move to include recycled asphalt shingles (RAS) in asphalt pavements, both containing highly aged binders and needing special attention. As such, there will be a need to compensate for the loss of asphalt quality through the use of additives and modifiers in asphalt. Furthermore, standards and specifications continue to become more stringent in demanding higher performance from binders so that pavement distresses are reduced. These higher performance expectations drive the demand for suitable additives and modifiers to deliver performance. Finally, there is the concern with depletion of crude oil and hence depletion of asphalt binder for road construction. Therefore, alternatives need to be sought, and there has been already a considerable amount of research to utilize bio-based binders to at least partially replace fossil-based asphalt binders.

There are different types of asphalt additives and modifiers. These include polymers, fibers, antistripping additives, chemical modifiers, and extenders. Polymers are the most commonly used additives and are often already incorporated into the asphalt refinery through terminal blending and typically not a concern on the side of the state highway agency as long as the modified binder meets required performance grade specifications. However, other additives may be added to the asphalt at the plant, and hence the need to have an approved list of such products. While elastomers and plastomers are among the polymers most commonly used in asphalt, crumb rubber modifiers (CRMs) also fall in the category of polymers and need special attention. Similar to polymer-modified asphalt, rubberized asphalt is produced at the terminal and must meet specifications. However, in many instances, CRM is added to the asphalt in the field, and therefore a list of approved CRM products is needed.

In regard to antistripping agents, PennDOT has been active in approving and including suitable agents in the bulletin. Recommendation is made to consider monitoring long-term performance of pavements in terms of evaluating effectiveness of antistripping agents in reducing moisture damage of asphalt pavements. This will be an important step, since currently the use of antistripping agents is mandatory for all asphalt mixes regardless of WMA technology or aggregate source.

An important group of additives that PennDOT is currently investigating is rejuvenating agents. While there are as yet no approved rejuvenating agents listed in Bulletin 15, the efforts by PennDOT in looking into these additives is commendable. With the use of RAS and high RAP, use of such additives becomes important and, in many cases, necessary so that pavement performance is not compromised and premature distresses do not develop in the asphalt pavement. Obviously, the rejuvenating agents must be vetted and explored for their effectiveness before they get approved by PennDOT, but certainly it is important that the Department continues its efforts toward approving these additives expeditiously.

Biobinders are perhaps best categorized as replacers of conventional binder rather than considered additives or modifiers. While depletion of conventional binder is not expected to occur immediately, it will happen and alternative binders must be ready. There might be even other circumstances in which demand may grow for alternative binders, such as continued deterioration of conventional binders, or unexpected price spikes, which may make use of bio-based binders more appealing. In any event, it is recommended that PennDOT begin considering these alternative binders and maybe include those that have demonstrated proven performance as candidates for approval and inclusion in Bulletin 15. Such a move will encourage use of these materials for partial replacement of fossil-based binders and may help with advancement of the bio-based technology research and implementation.

5.4 Chapter Summary

This chapter provided a review of the approved materials and additives used in concrete and asphalt projects in PennDOT District 4. In addition, it evaluated whether all such approved sources can lead to producing high-quality concrete and asphalt mixtures. This review included approved aggregate sources listed under Bulletin 14; approved portland cements, SCMs, admixtures and curing materials, and bituminous materials and additives listed under Bulletin 15; approved producers of bituminous materials listed under Bulletin 41; and producers of ready-mix concrete listed under Bulletin 42.

It was determined that the PennDOT-approval procedures for inclusion of materials and additives under the above bulletins as “pre-approved materials” or “pre-approved producers of concrete or bituminous materials” are in accordance with national standards and specifications such as ASTM and AASHTO. As such, provided that these approval procedures are carefully followed both for the initial certification and the annual quality control of the approved materials and producers, these approved materials should lead to producing high-quality concrete and asphalt mixtures. It is suggested that PennDOT list the publication year of the referenced ASTM and AASHTO standards to make sure that the latest versions of such standards are used to vet the prospective and current approved materials for concrete and asphalt projects.

Chapter 6. Recommendations on Short and Long-Term Remedial Actions and Rehabilitations

6.1 Concrete Sidewalks

In the authors' opinion, there is no meaningful short-term remediation strategy for scaled concrete sidewalks. Scaling may continue and progress to areas that have not yet scaled. Scaled concrete surface is not only aesthetically unpleasant, but it may also increase the risk of slip and fall as the rough surface may not drain properly, leading to ice accumulation. Otherwise, the sidewalk should be structurally sound. As such, in the short-term, the owner should make sure that the sidewalks are properly deiced in winter months to ensure the safety of pedestrians.

As a long-term strategy, the concrete sidewalk should be repaired by removing the weak, cracked, and scaled surface, followed by applying a durable overlay [26]. To accomplish this, sandblasting, high-pressure water jet (hydro-demolition), or diamond grinding can be used to remove all unsound surface concrete. For the Wilkes University sidewalks, the petrographic examination of concrete cores performed by American Engineering Testing, Inc. [1] suggested the depth of damaged carbonated concrete to be up to $^3/_8$ of an inch from the surface. As such, at a minimum, the top ½ inch of concrete from the surface should be removed. Careful visual inspection and sounding of the prepared surface should be conducted and loose or unsound concrete should be removed before placing the overlay. A follow-up petrographic examination may be necessary to make sure the base surface is strong and free of damage before application of the overlay. Since the repaired surface is only as strong as the base surface to which it is bonded, the base surface should be cleaned free of dirt, debris, oil, paint, and cracked/scaled concrete. The clean, rough, textured surface is then ready for a thin bonded resurfacing/overlay.

The choice of overlay material is important to ensure the longevity of the repair. More specifically, the overlay must be resistant to freezing and thawing in exposure to moisture and deicing salts. Also, the overlay must have low shrinkage and similar coefficient of thermal expansion as that of the substrate concrete to prevent strain incompatibility and cracking. Generally, portland cement concrete, proprietary pre-packaged mortar or concrete, or polymer-modified cement-based mortar or concrete are the best choices for overlays to be compatible with the existing concrete substrate.

A 2-to-3-inch portland cement concrete overlay with proper air entrainment and w/cm no larger than 0.45 could be recommended. Shrinkage compensating concrete or use of shrinkage reducing admixtures may be necessary to minimize the shrinkage and the risk of cracking in the overlay. Care must be taken to minimize water evaporation and risk of plastic shrinkage cracking during construction of the overlay. The overlay must be properly cured, ideally for 28 days. Proprietary pre-packaged concrete or mortar may be used for thinner overlays. However, performance-based contracting with the supplier may be necessary to ensure that the overlay performs as intended during construction and the service life of the sidewalk. The pre-packaged materials must comply with ASTM C928 [141]. Additionally, their ultimate unrestrained drying shrinkage must be limited to 0.1% [142]. Information on criteria for selecting proprietary repair mortars can be found in ACI 546.3R [143].

Polymer-modified concrete (also known as latex-modified concrete) is made of portland cement, aggregates, and organic polymers (such as styrene butadiene, acrylic, or vinyl acetate with ethylene) that are dispersed in water. These polymer dispersions are called "latex" and are added to the concrete mixture to improve the properties such as bond strength to substrate, flexibility and impact resistance, resistance to water and salt penetration, and resistance to freezing and thawing. Similarly, an epoxy dispersion in water can be used and mixed into concrete. Levels of 10% to 20% polymer solids by mass of cementitious materials are required for most applications. Typical w/cm for workable mixtures range from 0.30 to 0.40 for mixtures containing latex, and 0.25 to 0.35 for mixtures containing epoxy [144]. Polymer-modified concrete should be placed and cured at 45 to 85 °F with special precautions taken when either extreme is reached. Handling and finishing polymer-modified concrete is often limited to 30 minutes or less, so the contractor must be prepared for rapid installation. Special precautions are necessary to limit the water evaporation rate to 0.1 lb/ft^2h to prevent plastic shrinkage cracking. Epoxy emulsions are generally more expensive than latexes, and some are susceptible to color change and deterioration from exposure to sunlight. Polymer-modified mortars may be as thin as 0.75 inch while polymer-modified concrete should be 1.5 inches or thicker. Relevant specifications and standards include ACI 548.4, ASTM C1438, and ASTM C1439.

It is strongly recommended that the owner hire a contractor that is experienced in design and construction of concrete repairs, and specifically in repair of deteriorated concrete surfaces. The intended service life of the sidewalks should be considered as well. For selecting the most appropriate repair materials and methods, ACI 546R-14 "Guide to Concrete Repair" [145] and ACI 546.3R-14 "Guide to Materials Selection for Concrete Repair" [143] should be consulted. These guidance documents provide helpful descriptions for surface preparation and removal of unsound concrete, selection of repair and overlay materials, placement of the overlay, QC/QA practices, required maintenance after completion of repairs, and recommended practices for preparation of repair contract documents and the bidding or negotiation process.

6.2 Asphalt Pavements

Similar to concrete pavements, maintenance and rehabilitation of asphalt pavements is important to ensure the service life of the pavement. Depending on the types of asphalt pavement distresses, treatment or repair strategies are varied. Based on the intensity of the work involved and the timing of treatment, these treatments can be classified as routine maintenance, seal coating, minor rehabilitation, major rehabilitation, or reconstruction. Examples of routine maintenance and repair include crack sealing and various types of patching. Examples of seal coating include single and double-lay chip sealing and slurry seals. Minor rehabilitation, which is the most often used as a pavement preservation technique, deals with microsurfacing, thin asphalt overlays, and ultra-thin bonded wearing course. Finally, major rehabilitation and reconstruction deal with cases where base repair or total replacement of the pavement structure is needed.

Appropriate treatments can be selected depending on types of roadways and distresses. Roadways can be categorized depending on average daily traffic (ADT): NHS Expressway, NHS non-Expressway, Non-NHS (≥ 2,000 ADT), and Non-NHS (< 2,000 ADT). Types of distresses are fatigue cracking, transverse cracking, miscellaneous cracking, edge deterioration, raveling/weathering, left edge (centerline) joint deterioration, rutting, and excessive roughness. The severity of distresses, which is generally based on the percentage of the total segment length or area, is also important to determine the appropriate treatment method.

Asphalt pavement rehabilitation treatments, such as full-depth repair, partial-depth repair, or patching, cold milling, hot in-place recycling, cold in-place recycling, asphalt overlay [146], full-depth, partial-depth, or patching can be considered if there is localized deterioration in asphalt pavements. Full-depth and partial-depth repairs mean repair down to subgrade and surface repair, respectively. Maintenance patching is a temporary repair. Cold milling is performed by removing existing pavement surface for texturizing the surface prior to the resurfacing work. This patching rehabilitation method has been used for the repair of thermal segregation of asphalt pavement [147]. Hot in-place recycling is conducted for the rejuvenation of existing aged asphalt pavements. This is beneficial for improving bond and preventing reflection cracking. Cold in-place recycling can be performed by cold milling of existing asphalt concrete, mixing of milled materials with emulsified asphalt and other additives, and placement and compaction of materials. Cold in-place recycled materials tend to have low stiffness compared to hot-mix asphalt. Asphalt overlay is applied for improving riding quality and surface frictional properties. The ultimate performance of the asphalt concrete pavement depends on the thickness of structural layers, mixture design, and condition of existing pavements. Usually, thickness of asphalt paving overlay is in a range of 1.5–2.5 inches over the existing pavement.

Deciding the remedial action with segregated asphalt pavements is more challenging compared to distressed conditions such as rutting and cracking. One reason is that rutting and cracking are more easily identified, as they are more visible and easier to measure. Segregated pavements are sometimes difficult to identify, as they do not necessarily manifest surface distresses; rather, they are highly prone to gradual development of various types of distresses such as cracking, raveling, frost damage, and potholes with time. This is the case because segregated pavements tend to have a weaker asphalt mix, higher void content, less asphalt content, and higher water permeability.

The first challenge is identification of the segregation and determination of the level of severity. Once visual observation indicates potential for segregation, a test must be conducted to verify the case and establish the level of severity. Typical tests conducted by many highway agencies include the sand patch method (PTM 751 [148], or ASTM E965 [149]), which delivers mean texture depth (MTD). The test takes advantage of the area covered by a known volume of glass beads. Dividing the volume into the covered area gives MTD. Laser-based techniques such as the one used in Circular Track Meter (CMT, ASTM E2157 [150]) or vehicle-mounted device (ROSAN) also provide a measure of the mean profile depth (MPD). ASTM E1845 [151] covers standard practice for calculating pavement macrotexture MPD. Strong correlations have been reported by the sand patch method and laser-based techniques. Based on the test results, the severity of segregation could be classified as none, low, intermediate, or high. Typically, coring of the suspected area is also needed to identify severity. The gradation of the segregate area tends to be coarse and the asphalt content tends to be lower for the segregated portion of the mat compared to the non-segregated portion of the mat.

The type of remedial action to be taken is decided based on the severity of segregation and the extension of segregation area and length. In case of low severity and small affected areas, it may be decided not to take any action. In case of moderate or high severity, the remedial action could be targeted patching repair or removing and replacing the mat depending on the severity of segregation. For SR 1016, coring could take place to identify the level of severity. NCHRP Report 441 (152) [146] can be used as a guide in deciding the level of segregation severity and the remedial actions to be taken.

As reflected in Specification 408 Section 413, PennDOT considers a pavement segregated if MTD exceeds 0.024 inch, and in that case requires coring from segregated and non-segregated sections and determination of density, gradation, and asphalt content. If the test results indicate defective pavement, the full width of the affected area plus a minimum of 5 ft beyond each end of the defective area must be removed and replaced. As PennDOT tends to move toward performance-based specifications, it is recommended that performance-based testing be considered in deciding whether the segregated area needs to be removed and replaced or be considered for adjustment of pay factors. An example of such test is indirect tensile test for determination of strength and stiffness under both dry and wet conditions. Decision on remove/replace or pay adjustment could be made based on the level of strength and stiffness loss from this test. Such testing, for example, could be applied to the cores taken from SR 1016.

6.3 Chapter Summary

In this chapter, recommended short-term and long-term rehabilitation actions for the deteriorated concrete sidewalks and asphalt pavements were provided. For concrete sidewalks, the short-term strategy is to ensure proper deicing of the sidewalks to prevent the risk of slip and fall to pedestrians. In the long-term, the concrete sidewalk should be repaired by removing the cracked and scaled surface, followed by application of a durable overlay. Proper methods for removal of unsound concrete, surface preparation of the substrate, and selection of proper overlay materials were discussed.

Several treatment strategies were presented for asphalt pavement repair, maintenance, or preservation. These vary from minor repair to major rehabilitation or reconstruction depending on the type and extension of the distresses. In regard to asphalt mix segregation, a summary of available techniques to identify the severity of segregation was discussed. It is best to decide the remedial action depending on the severity and extension of segregation. These actions include full-depth repair, partial-depth repair, patching, or complete removal and replacement of the pavement mat. Considering low to moderate severity of segregation on SR1016 and SR2020 in District 4, it is recommended that performance testing be conducted on the cores taken from the pavement and decision on the remedial action be taken based on laboratory performance test results.

Chapter 7. Overall Conclusions and Recommendations

In this project, a team of Penn State researchers conducted a comprehensive evaluation of the current and recent PennDOT specifications relevant to concrete flatwork (primarily sidewalks) and asphalt pavements. This evaluation was triggered by the recent premature deterioration of concrete sidewalks in the City of Wilkes-Barre, PA and the segregation of asphalt pavements at SR1016 and SR2020 in the vicinity of the town of Olyphant, PA. The causes of the observed distresses were identified based on a review of the construction documents and a site visit/inspection. The governing PennDOT specifications were compared with the relevant state-of-the-art research results from the literature, the national standards and specifications, as well as the specifications from six other state DOTs (Michigan, Minnesota, North Carolina, Texas, Virginia, and Wisconsin). Additionally, a review of the PennDOT-approved materials and additives used in concrete and asphalt projects in District 4 were performed. Finally, recommendations for repairing the existing damaged structures in District 4 were offered.

Based on the findings and other information collected in this project, the following overall conclusions and recommendations are offered:

<u>Conclusions related to concrete sidewalks:</u>

- The following factors are the most likely causes of the observed surface scaling of concrete sidewalks on the Wilkes University campus: (a) Concrete had an excessive amount of slag, beyond the dosage that was needed to mitigate ASR. (b) Concrete had excessive slump. (c) The sidewalks were built using PennDOT Class A concrete, which is not an appropriate choice for concrete that is exposed to freezing and thawing, and is in continuous contact with moisture, and is exposed to deicing chemicals.
  (d) Concrete finishing and curing practices were likely inadequate.

- Mitigation of the scaling risk in exterior concrete flatwork (e.g., sidewalks) starts with the design and selection of a good quality dense concrete mixture that has a low w/cm (< 0.47 and preferably < 0.45), proper slump (< 5 inches), and adequate entrained air (6.0% target). If reactive aggregates are present, a sufficient SCM dosage to mitigate ASR must be used. However, excessive SCM quantities must be avoided as they may lead to significant delays in setting and increased risk of surface scaling of concrete.

- To mitigate scaling, good construction, finishing, and curing practices for concrete are critical. After floating, any additional finishing (such as edging, jointing, smoothing, and texturing) must wait until after concrete has passed initial setting, bleeding has completed, and the bleed water has evaporated or has been removed using a hose drag. Excessive finishing and smoothing of sidewalk surfaces are not needed and increase the scaling risk. Air-entrained concrete should not be troweled. Use of Fresno and power trowels must be avoided. Intricate finishing operations that require excessive hand-finishing must be avoided if possible. Reworking of bleed water into the surface or adding water or monomolecular film to make finishing easier (a practice known as "blessing" the concrete) result in a weak and high-porosity surface, prone to scaling and cracking. These practices must be absolutely avoided.

- Appropriate curing is also critical to ensure that concrete achieves its full potential and to reduce the scaling risk. Curing for 7 days using liquid membrane-forming curing compounds or water curing as specified in Section 1001.3(p) of Publication 408/2020-2 should be employed. Curing must be commenced immediately after finishing. Care must be taken to make sure the exposed concrete surfaces never dry out. If curing is delayed for any reason, an intermediate monomolecular film curing agent must be applied to protect the surface. After conclusion of curing, application of a breathable sealer (e.g., silane, siloxanes, or boiled linseed oil) is recommended to protect the concrete from deicing salt scaling. The sealer creates a protective barrier to minimize penetration of water and deicing chemicals into concrete. Generally, sealants with solid contents of 25% or higher are recommended.

- Using deicing chemicals within the first few months after construction of concrete sidewalks is discouraged. Instead, clean sand should be used for traction. Deicing chemicals composed of calcium chloride and sodium chloride (rock salt) are acceptable for concrete but ammonium sulfate, ammonium nitrate, or magnesium-based salts must be avoided as they are chemically aggressive and harmful to concrete surfaces.

- In comparison with states with similar or colder climate, PennDOT's current specifications for concrete sidewalks allow for a higher w/cm, a higher SCM content, and a higher slump. These factors increase the risk of surface damage in concrete flatwork.

- To improve the quality and longevity of concrete pavements, in recent years, PennDOT has significantly improved its specifications. This includes raising the quality requirements for Class AA concrete by reducing the allowable maximum w/cm and increasing the allowable minimum 28-day strength. PennDOT has also expanded the requirements for construction and curing, including limiting the allowable water evaporation rate, disallowing the use of steel or Fresno floats, and prohibiting the addition of water or monomolecular film to the concrete surface to assist in finishing. Similar mix design and construction requirements should be considered for concrete sidewalks.

- PennDOT approval procedures for inclusion of materials and additives under its construction bulletins as "pre-approved materials" or "pre-approved producers of concrete or bituminous materials" are in accordance with national standards and specifications such as ASTM and AASHTO. Provided that these approval procedures are carefully followed both for the initial certification and the annual quality control of the approved materials and producers, these approved materials should lead to producing high-quality concrete and asphalt mixtures. It is suggested that PennDOT list the publication year of the referenced ASTM and AASHTO standards within its approval protocols to make sure that the latest versions of such standards are used to vet the prospective and current approved materials for concrete and asphalt projects.

Recommendations related to concrete sidewalks:

- Class AA Cement Concrete for Form Paving according to Table A of Publication 408 Section 501.2 is recommended for sidewalk construction. This would limit the allowable maximum w/cm to 0.45 and sets the required minimum 28-day compressive strength at 4,000 psi. Additionally, the maximum allowable slump should be 5 inches.

- The following changes to PennDOT Publication 408 are recommended:
  - Section 676: Cement Concrete Sidewalks:
    - 676.2: Replace “Class A Cement Concrete” with “Class AA Cement Concrete for Form Paving according to Table A of Section 501.2”
    - Add: “The maximum allowable slump is 5 inches.”
    - Add: “Do not use vibratory screeds when concrete target slump is over 3 inches.”
    - Add: “After floating and straightedge testing, any additional finishing of concrete surface must wait until after the bleeding has completed and the bleed water has evaporated or has been removed, and after the initial setting of concrete. Adding water to make finishing easier or reworking of bleed water into fresh concrete surface are not permitted. Excessive finishing or troweling of the concrete surface using Fresno and power trowel are not permitted.”
    - Add: “Curing must be commenced immediately after finishing. Care must be taken to make sure the exposed concrete surfaces never dry out. If curing is delayed for any reason, an intermediate monomolecular film curing agent must be applied to protect the surface.”
  - Section 704: Cement Concrete
    - Add: “For prevention of alkali-silica reaction (ASR), the dosage level of supplementary cementitious materials (SCM) beyond values prescribed in 704.1(g)2.b are not recommended as they may cause excessive retardation of setting and strength development of concrete at early ages. This can be critical in cool and cold weather construction. Plans to mitigate such retardation effects and ensure proper construction and curing of concrete containing SCM must be presented to the Department for approval.”
    - Add language to ensure that ACI-certified Flatwork Finishers or NRMCA-certified Exterior Flatwork Finishers are employed by the contractor to finish concrete projects including concrete pavements and sidewalks.

- For repair of scaled sidewalks in District 4, it is recommended to remove the cracked and scaled surface (to a minimum of ½ inch depth from the surface), followed by application of a durable overlay. Proper methods for removal of unsound concrete, surface preparation of the substrate, and selection of proper overlay materials are discussed in Chapter 6.

Conclusions and recommendations related to asphalt pavements:

- Current volumetric properties-based asphalt mixture design is appropriate. The low-moderate thermal segregation issues on SR 1016 and SR 2020 are caused by cold weather paving. Cold weather paving is a challenge in many states. Special attention is needed (e.g., insulated trucks, higher temperatures, thicker layers, warm-mix asphalt additives) to avoid thermal segregation.

- To reduce potential risk of thermal segregation, application of thermal imaging camera can be considered. This system can monitor temperatures of asphalt mat during the laydown and paving operation.

- The implementation of reclaimed binder ratio based on total asphalt binder content can be considered. The amount of asphalt binder plays an important role in performance of asphalt mixtures. Many other states have already adopted this criterion rather than reclaimed binder content based on total asphalt mixtures, which is the current criterion in Pennsylvania.

- Improvements with respect to asphalt pavement specifications can be made with the utilization of balanced mix design and performance-based testing. Based on the results of performance tests of asphalt concrete, potential performance issues can be avoided. According to the survey conducted by this study, it was reported that Minnesota and Virginia DOTs are interested in balanced mix design. In the case of Virginia DOT, it is planning to implement balanced mix design method in 2023.

- In addition, some improvements can be considered regarding assessing the tack bond strength, inclusion of recycling agents, and revisions to gyration levels for different traffic levels.

- In asphalt pavements having low to moderate severity of thermal segregation, no urgent repairs or maintenance practices are needed. To prevent further quality issues, monitoring the deteriorated asphalt pavements is more appropriate.

References

[1] ECMS Highway Construction Contract 104323, Nov. 30, 2016, Pennsylvania Department of Transportation.

[2] Wilkes University Sidewalk Project QC/QA Results, Received 1/26/21 from Mr. Robert McGowan, PennDOT District 4.

[3] Email from Mr. Robert McGowan to Penn State, dated 1-25-2021.

[4] K. Amini, H. Ceylan, P.C. Taylor, Effect of finishing practices on surface structure and salt-scaling resistance of concrete, Cem. Concr. Compos. 104 (2019).

[5] W.H. Chesner, R.J. Collins, M.H. MacKay, User guidelines for waste and byproduct materials in pavement construction, 1998.

[6] Email from Mr. Robert McGowan to District 4 concrete producers, dated 6-29-2018.

[7] ACI 211.1-91, Standard Practice for Selecting Proportions for Normal, Heavyweight, and Mass Concrete, American Concrete Institute (1991).

[8] H.B. Prenger, NRMCA Report Best Practices for Exterior Flatwork Finishing, National Ready Mix Concrete Association (NRMCA), 2017.

[9] Documents related to the 2019 resurfacing of asphalt roadways in Lackawanna Co., PA: B. Hilburt, Job Mix Formula Report W95222E2, Submitted by New Enterprise Stone & Lime Co. to PennDOT, 2019.

[10] Documents related to the 2019 resurfacing of asphalt roadways in Lackawanna Co., PA: Asphalt Pavement Testing Report (Exhibit M), 2019.

[11] Documents related to the 2019 resurfacing of asphalt roadways in Lackawanna Co., PA: Weather Observations at the Wilkes-Barre/Scranton Airport (Exhibit R), 2019.

[12] Documents related to the 2019 resurfacing of asphalt roadways in Lackawanna Co., PA: Email from William D. Faux to Ms. Catherine Daniels, dated 9-9-2019 (Exhibit H).

[13] Documents related to the 2019 resurfacing of asphalt roadways in Lackawanna Co., PA: Email from Josef R. Whitcomb to Ms. Catherine Daniels, dated 10-4-2019 (Exhibit I).

[14] Documents related to the 2019 resurfacing of asphalt roadways in Lackawanna Co., PA: Email from Josef R. Whitcomb to Ms. Catherine Daniels, dated 10-23-2019 (Exhibit J).

[15] K. Wang, D.E. Nelsen, W.A. Nixon, Damaging effects of deicing chemicals on concrete materials, Cem. Concr. Compos. 28 (2006) 173–188.

[16] J. Yuan, Z. Du, Y. Wu, F. Xiao, Freezing-thawing resistance evaluations of concrete pavements with deicing salts based on various surfaces and air void parameters, Constr. Build. Mater. 204 (2019) 317–326.

[17] NRMCA Concrete in Practice: CIP 14 - Finishing Concrete Flatwork, National Ready Mix Concrete Association (NRMCA), 2017.

[18] NCHRP Report 577 Guidelines for the Selection of Snow and Ice Control Materials to Mitigate Environmental Impacts, National Cooperative Highway Research Program (NCHRP), 2007.

[19] Steven H. Kosmatka, Michelle L. Wilson, Design and Control of Concrete Mixtures, Sixteenth edition, Portland Cement Association, 2016.

[20] S. Jin, J. Zhang, B. Huang, Fractal analysis of effect of air void on freeze-thaw resistance of concrete, Constr. Build. Mater. 47 (2013) 126–130.

[21] P. Gao, S. Wu, P. Lin, Z. Wu, M. Tang, The characteristics of air void and frost resistance of RCC with fly ash and expansive agent, Constr. Build. Mater. 20 (2006) 586–590.

[22] J.J. Valenza, G.W. Scherer, A review of salt scaling: I. Phenomenology, Cem. Concr. Res. 37 (2007) 1007–1021.

[23] P.K. Mehta, P.J.M. Monteiro, Concrete: Microstructure, Properties, and Materials, McGraw Hill Professional, 2013.
[24] ACI 201.2R-16, Guide to Durable Concrete, American Concrete Institute (2016).
[25] P. Suraneni, J. Monical, E. Unal, Y. Farnam, J. Weiss, Calcium oxychloride formation potential in cementitious pastes exposed to blends of deicing salt, ACI Mater. J. 114 (2017) 631–641.
[26] NRMCA Concrete in Practice: CIP 2 - Scaling Concrete Surfaces, National Ready Mix Concrete Association (NRMCA), (2014).
[27] ACI 318-19, Building Code Requirements for Structural Concrete and Commentary, American Concrete Institute, (2019).
[28] ASTM C457/C457M-16, Standard Test Method for Microscopical Determination of Parameters of the Air-Void System in Hardened Concrete, (2016).
[29] M. Alexander, A. Bentur, S. Mindess, Durability of Concrete Design and Construction, CRC Press, (2017).
[30] PowerPoint Presentation by J. Casilio titled , "Reducing Scaling of Concrete Surfaces," Pennsylvania Aggregates and Concrete Association, (2021).
[31] S. Mindess, J.F. Young, D. Darwin, Concrete, 2nd ed., Prentice Hall, (2003).
[32] ACI 308R-16, Guide to External Curing of Concrete, American Concrete Institute (2016).
[33] K. Amini, H. Ceylan, P.C. Taylor, Effect of curing regimes on hardened performance of concrete containing slag cement, Constr. Build. Mater. 211 (2019) 771–778.
[34] P. Suraneni, V.J. Azad, O.B. Isgor, W.J. Weiss, Use of fly ash to minimize deicing salt damage in concrete pavements, Transp. Res. Rec. J. Transp. Res. Board. 2629 (2017) 24–32.
[35] K. Amini, P. Vosoughi, H. Ceylan, P. Taylor, Linking air-void system and mechanical properties to salt-scaling resistance of concrete containing slag cement, Cem. Concr. Compos. 104 (2019) 103364.
[36] S. Tavasoli, M. Nili, B. Serpoosh, Effect of GGBS on the frost resistance of self-consolidating concrete, Constr. Build. Mater. 165 (2018) 717–722.
[37] Z. Giergiczny, M.A. Glinicki, M. Sokołowski, M. Zielinski, Air void system and frost-salt scaling of concrete containing slag-blended cement, Constr. Build. Mater. 23 (2009) 2451–2456.
[38] E. Özbay, M. Erdemir, H.I. Durmuş, Utilization and efficiency of ground granulated blast furnace slag on concrete properties - A review, Constr. Build. Mater. 105 (2016) 423–434.
[39] N. Bouzoubaâ, A. Bilodeau, B. Fournier, R.D. Hooton, R. Gagné, M. Jolin, Deicing salt scaling resistance of concrete incorporating supplementary cementing materials: Laboratory and field test data, Can. J. Civ. Eng. 35 (2008) 1261–1275.
[40] ASTM C672/C672M-12, Standard Test Method for Scaling Resistance of Concrete Surfaces Exposed to Deicing Chemicals, (2012).
[41] ASTM C511-19, Standard Specification for Mixing Rooms, Moist Cabinets, Moist Rooms, and Water Storage Tanks Used in the Testing of Hydraulic Cements and Concretes, (2019).
[42] ASTM C1293-20, Standard Test Method for Determination of Length Change of Concrete Due to Alkali-Silica Reaction, (2020).
[43] ACI 332-14, Residential Code Requirements for Structural Concrete and Commentary, American Concrete Institute (2014).
[44] Reduce Scaling with Slag Cement and Good Concreting Practices, Slag Cement Association, (2013).
[45] R.D. Hooton, D. Vassilev, CP Tech Center Report: Deicer scaling resistance of concrete

mixtures containing slag cement, phase 2: Evaluation of different laboratory scaling test methods, Natl. Concr. Pavement Technol. Cent. (CP Tech Center). (2012).
[46] ACI Certificate Programs: Concrete Flatwork Associate, Finisher, and Advanced Finisher, (2019). https://www.concrete.org/certification/certificationprograms.aspx?m=details&pgm=Concrete Flatwork Finishing&cert=Concrete Flatwork Associate, Finisher, and Advanced Finisher (accessed March 22, 2021).
[47] NRMCA Exterior Flatwork Finisher Certification, National Ready Mix Concrete Association (NRMCA), (2020).
[48] H.B. Prenger, Finishing the Sidewalk Scaling Situation, Concr. Int. 40 (2018) 36–38.
[49] PennDOT Publication 37 (Bulletin 25), (2018).
[50] AASHTO M 320-17, Standard Specification for Performance-Graded Asphalt Binder, (2017).
[51] AASHTO T 48-18, Standard Method of Test for Flash Point of Asphalt Binder by Cleveland Open Cup, (2018).
[52] AASHTO T 316-19, Standard Method of Test for Viscosity Determination of Asphalt Binder Using Rotational Viscometer, (2019).
[53] AASHTO T 315-20, Standard Method of Test for Determining the Rheological Properties of Asphalt Binder Using a Dynamic Shear Rheometer (DSR), (2020).
[54] AASHTO T 313-19, Standard Method of Test for Determining the Flexural Creep Stiffness of Asphalt Binder Using the Bending Beam Rheometer (BBR), (2019).
[55] AASHTO T 314-12, Standard Method of Test for Determining the Fracture Properties of Asphalt Binder in Direct Tension (DT), (2012).
[56] AASHTO T 240-13, Standard Method of Test for Effect of Heat and Air on a Moving Film of Asphalt Binder (Rolling Thin-Film Oven Test), (2013).
[57] AASHTO R 28-12, Standard Practice for Accelerated Aging of Asphalt Binder Using a Pressurized Aging Vessel (PAV), (2016).
[58] AASHTO M 332-20, Standard Specification for Performance-Graded Asphalt Binder Using Multiple Stress Creep Recovery (MSCR) Test, (2020).
[59] AASHTO T 350-19, Standard Method of Test for MMultiple Stress Creep Recovery (MSCR) Test of Asphalt Binder Using a Dynamic Shear Rheometer (DSR), (2019).
[60] PennDOT Publication 27 (Bulletin 27), Bituminous Concrete Mixtures, Design Procedures, and Specifications for Special Bituminous Mixtures, (2003).
[61] AASHTO M 323-17, Standard Specification for Superpave Volumetric Mix Design, (2017).
[62] AASHTO T 312-19, Standard Method of Test for Preparing and Determining the Density of Asphalt Mixture Specimens by Means of the Superpave Gyratory Compactor, (2019).
[63] M.C. Rubio, G. Martínez, L. Baena, F. Moreno, Warm mix asphalt: An overview, J. Clean. Prod. 24 (2012) 76–84.
[64] B.A. Williams, A. Copeland, T.C. Ross, NAPA Report Asphalt Pavement Industry Survey on Recycled Materials and Warm-Mix Asphalt Usage, (2017).
[65] FHWA Report: Warm-Mix Asphalt: European Practice, Federal Highway Administration (FHWA), (2008).
[66] A. Vaitkus, V. Vorobjovas, L. Žalimienė, The research on the use of warm mix asphalt for asphalt Pavement structures, in: XXVII Int. Balt. Road Conf., Riga, Latvia, (2009).
[67] A. Faheem, B. Abboud, J. Coe, M. Alsalihi, PennDOT Report: Effect of Warm Mix Asphalt (WMA) Low Mixing and Compaction Temperatures on Recycled Asphalt Pavement (RAP) Binder Replacement, Pennsylvania Dep. Transp. (2018).
[68] FHWA Report: The Effect of WMA on RAP in Hot Mix Asphalt, Federal Highway

Administration (FHWA), (2015).
[69] B. Hill, Performance Evaluation of Warm Mix Asphalt Mixtures Incorporating Reclaimed Asphalt Pavement, University of Illinois at Urbana-Champaign, (2011).
[70] AASHTO R 35-17, Standard Practice for Superpave Volumetric Design for Asphalt Mixtures, (2017).
[71] R. McDaniel, R.M. Anderson, NCHRP Report 452 Recommended Use of Reclaimed Asphalt Pavement in the Superpave Mix Design Method: Technician's Manual, National Cooperative Highway Research Program (NCHRP), (2001).
[72] FHWA Report: Reclaimed Asphalt Pavement in Asphalt Mixtures: State of the Practice, Federal Highway Administration (FHWA), (2011).
[73] J.A. Musselman, R. Moraes, T.B. Walbeck, R.C. West, NAPA Report Agency Guidelines for Addressing Tack Tracking, (2020).
[74] T. Aschenbrener, F. Leiva, N. Tran, FHWA Report Demonstration Project for Enhanced Durability of Asphalt Pavements through Increased In-place Pavement Density, Phase 2, (2019).
[75] FHWA Tech Brief Report: Superpave Mix Design and Gyratory Compaction Levels, Federal Highway Administration (FHWA), (2010).
[76] AASHTO T 283-14, Standard Method of Test for Resistance of Compacted Asphalt Mixtures to Moisture-Induced Damage, (2018).
[77] D. Christensen, D. Morian, W. Wang, PennDOT Report: Cost Benefit Analysis of Anti-Strip Additives in Hot Mix Asphalt with Various Aggregates, Pennsylvania Dep. Transp. (2015).
[78] O. Kristjansdottir, Warm Mix Asphalt for Cold Weather Paving, University of Washington, (2006).
[79] M. Kim, P. Phaltane, L.N. Mohammad, M. Elseifi, Temperature segregation and its impact on the quality and performance of asphalt pavements, Front. Struct. Civ. Eng. 12 (2018) 536–547.
[80] F. Yin, R. West, NAPA Report Balanced Mix Design Resource Guide, Natl. Asph. Pavement Assoc. (2021).
[81] AASHTO PP 105-20, Standard Practice for Balanced Design of Asphalt Mixtures, (2020).
[82] FHWA Tech Brief Report: State of the Knowledge for the Use of Asphalt Mixtures with Reclaimed Binder Content, Federal Highway Administration (FHWA), (2018).
[83] NCHRP Report 752: Improved Mix Design, Evaluation, and Materials Management Practices for Hot Mix Asphalt with High Reclaimed Asphalt Pavement Content, National Cooperative Highway Research Program (NCHRP), (2013).
[84] NCHRP Report 927 Evaluating the Effects of Recycling Agents on Asphalt Mixtures with High RAS and RAP Binder Ratios, National Cooperative Highway Research Program (NCHRP), (2019).
[85] M.A. Dalhat, H.I. Al-Abdul Wahhab, Performance of recycled plastic waste modified asphalt binder in Saudi Arabia, Int. J. Pavement Eng. 18 (2017) 349–357.
[86] Special Specification 3074: Superpave Mixtures – Balanced Mix Design, (2019).
[87] Michigan DOT Standard Specifications for Construction, (2012). https://mdotjboss.state.mi.us/SpecProv/specBookHome.htm.
[88] Minnesota DOT Standard Specifications for Construction, (2018). http://www.dot.state.mn.us/pre-letting/spec/.
[89] North Carolina DOT Standard Specifications for Roads and Structures, (2018). https://connect.ncdot.gov/resources/Specifications/Pages/2018-Specifications-and-Special-Provisions.aspx.
[90] Texas DOT Standard Specifications for Construction and Maintenance of Highways,

Streets, and Bridges, (2014). https://www.txdot.gov/business/resources/txdot-specifications.html.
[91] Virginia DOT Road and Bridge Specifications, (2020). http://www.virginiadot.org/business/const/spec-default.asp.
[92] Wisconsin DOT Standard Specifications for Highway and Structure Construction, (2021). https://wisconsindot.gov/Pages/doing-bus/eng-consultants/cnslt-rsrces/rdwy/stndspec.aspx.
[93] ASTM C595/C595M-20, Standard Specification for Blended Hydraulic Cements, 2020.
[94] ASTM C494/C494M-19, Standard Specification for Chemical Admixtures for Concrete, (2019).
[95] AASHTO T 152-19, Standard Method of Test for Air Content of Freshly Mixed Concrete by the Pressure Method, (2019).
[96] AASHTO T 196M/T196-11 (2019), Standard Method of Test for Air Content of Freshly Mixed Concrete by the Volumetric Method, (2019).
[97] ASTM C1260-14, Standard Test Method for Potential Alkali Reactivity of Aggregates (Mortar-Bar Method), (2014).
[98] ASTM C309-19, Standard Specification for Liquid Membrane-Forming Compounds for Curing Concrete, (2019).
[99] AASHTO M 182-05 (2017), Standard Specification for Burlap Cloth Made from Jute or Kenaf and Cotton Mats, (2017).
[100] ASTM C227-10, Standard Test Method for Potential Alkali Reactivity of Cement-Aggregate Combinations (Mortar-Bar Method), (2010).
[101] AASHTO T 11-20, Standard Method of Test for Materials Finer Than 75-µm (No. 200) Sieve in Mineral Aggregates by Washing, (2020).
[102] AASHTO T 27-20, Standard Method of Test for Sieve Analysis of Fine and Coarse Aggregates, (2020).
[103] Z. You, C. Gilbertson, T. Van Dam, MDOT Report: Identifying Best Practices in Pavement Design, Materials, Construction, and Maintenance in Wet Freeze Climates Similar to Michigan, Michigan Dep. Transp. (2018).
[104] R. Kuehl, J. Korzilius, M. Marti, MNDOT Report: Synopsis of Recycled Asphalt Pavement (RAP) Material, Minnesota Dep. Transp. (2016).
[105] E.J. Hoppe, S. Lane, G.M. Fitch, S. Shetty, VDOT Report: Feasibility of Reclaimed Asphalt Pavement (RAP) Use As Road Base and Subbase Material, Virginia Dep. Transp. (2015).
[106] AASHTO R 80-17, Standard Practice for Determining the Reactivity of Concrete Aggregates and Selecting Appropriate Measures for Preventing Deleterious Expansion in New Concrete Construction, (2017).
[107] AASHTO T 24M/T 24-15 (2019), Standard Method of Test for Obtaining and Testing Drilled Cores and Sawed Beams of Concrete, (2015).
[108] PennDOT Bulletin 14 Supporting Information, (2021).
[109] AASHTO T 19M/T 19-14 (2018), Standard Method of Test for Bulk Density (Unit Weight) and Voids in Aggregate, (2018).
[110] AASHTO T 85-14(2018), Standard Method of Test for Specific Gravity and Absorption of Coarse Aggregate, (2018).
[111] AASHTO T 84-13(2017), Standard Method of Test for Specific Gravity and Absorption of Fine Aggregate, (2017).
[112] PennDOT Test Method PTM No. 510, Soundness of Aggregate by Use of Sodium Sulfate, (2013).
[113] AASHTO T 304-17, Standard Method of Test for Uncompacted Void Content of Fine Aggregate, (2020).

[114] AASHTO T 176-17, Standard Method of Test for Plastic Fines in Graded Aggregates and Soils by Use of the Sand Equivalent Test, (2017).
[115] AASHTO T 21M/T 21-20, Standard Method of Test for Organic Impurities in Fine Aggregates for Concrete, (2021).
[116] PennDOT Test Method PTM No. 100, Amount of Material Finer than 75 µm (No. 200) Sieve in Aggregate, (2018).
[117] PennDOT Test Method PTM No. 501, Determination of Fineness Modulus of Fine Aggregates, (2013).
[118] AASHTO T 96-02 (2019), Standard Method of Test for Resistance to Degradation of Small-Size Coarse Aggregate by Abrasion and Impact in the Los Angeles Machine, (2019).
[119] AASHTO T 327-12(2016), Standard Method of Test for Resistance of Coarse Aggregate to Degradation by Abrasion in the Micro-Deval Apparatus, (2016).
[120] ASTM D4791-19, Standard Test Method for Flat Particles, Elongated Particles, or Flat and Elongated Particles in Coarse Aggregate, (2019).
[121] ASTM D5821-13(2017), Standard Test Method for Determining the Percentage of Fractured Particles in Coarse Aggregate, (2017).
[122] PennDOT Test Method PTM No. 518, Hand Specimen Petrographic Examination, (2013).
[123] PennDOT Test Method PTM No. 519, Wet-Dry Durability Test, (2018).
[124] PennDOT Test Method PTM No. 620, Friable Particles, (2013).
[125] ASTM C33/C33M-18, Standard Specification for Concrete Aggregates, (2018).
[126] AASHTO M 6-13(2018), Standard Specification for Fine Aggregate for Hydraulic Cement Concrete, (2018).
[127] AASHTO M 80-13(2017), Standard Specification for Coarse Aggregate for Hydraulic Cement Concrete, (2017).
[128] PennDOT Bulletin 15 Supporting Information, (2021).
[129] ASTM C150/C150M-20, Standard Specification for Portland Cement, (2020).
[130] AASHTO M 295-19, Standard Specification for Coal Fly Ash and Raw or Calcined Natural Pozzolan for Use in Concrete, (2019).
[131] AASHTO M 302-19, Standard Specification for Slag Cement for Use in Concrete and Mortars, (2019).
[132] AASHTO M 307-13(2017), Standard Specification for Silica Fume Used in Cementitious Mixtures, (2017).
[133] ASTM C171-20, Standard Specification for Sheet Materials for Curing Concrete, 2020.
[134] AASHTO M 233-86(2019), Standard Specification for Boiled Linseed Oil Mixture for Treatment of Portland Cement Concrete, (2019).
[135] AASHTO M194M/M194-13(2017), Standard Specification for Chemical Admixtures for Concrete, (2017).
[136] AASHTO M 154M/M 154-12(2020), Standard Specification for Air-Entraining Admixtures for Concrete, (2020).
[137] ASTM C979/C979M-16, Standard Specification for Pigments for Integrally Colored Concrete, (2016).
[138] PennDOT Bulletin 42 Supporting Information, (2021).
[139] ASTM D1073-16, Standard Specification for Fine Aggregate for Asphalt Paving Mixtures, (2016).
[140] ASTM D692/D692M-20, Standard Specification for Coarse Aggregate for Asphalt Paving Mixtures, (2020).
[141] ASTM C928/C928M-20a, Standard Specification for Packaged, Dry, Rapid-Hardening Cementitious Materials for Concrete Repairs, (2020).

[142] UFGS 03 01 32 Concrete Rehabilitation For Civil Works, U.S. Army Corps Eng. (2009).
[143] ACI 546.3R-14 Guide to Materials Selection for Concrete Repair, American Concrete Institute (2014).
[144] ACI 548.1R-09 Guide for the Use of Polymers in Concrete, American Concrete Institute (2009).
[145] ACI 546R-14 Guide to Concrete Repair, American Concrete Institute (2014).
[146] M. Stroup-Gardiner, E.R. Brown, NCHRP Report 441: Segregation in Hot-Mix Asphalt Pavements, National Cooperative Highway Research Program (NCHRP), (2000).

Appendix: Survey Responses from the DOTs

❖ From PennDOT – Central Office

General questions:

1. What have been the recent challenges and concerns regarding design and construction of concrete and asphalt pavements over the last 5 years? Have PennDOT specifications been revised to address these challenges? If not, what prevented a change in the specifications?
➔ Concrete: • Currently experiencing joint construction concerns • Implemented Long Life Concrete specification including optimized mix design ➔ Asphalt - Challenges/Concerns: • Industry increased frequency of proposing to use RAP (>15%) and high RAP (>25%) in asphalt mixtures. • Long-term performance of some dense-graded Superpave volumetric asphalt mixture designed asphalt pavements (cracking, delamination) • Performance of some longitudinal joints between lanes. ➔ Asphalt - Specification Changes • Concerning high RAP (>25%), PennDOT implemented Standard Special Provisions (SSPs) for high RAP for low volume roadways for use in 100% state funded, non-NHS, paving applications for dense-graded Superpave volumetric asphalt mixture designed asphalt pavements. Two SSPs have been implemented (one for 9.5 mm NMAS Wearing Courses and one for 19 mm NMAS Binder Courses). A third SSP, for 25.0 mm NMAS Base Courses is under the final stages of implementation. These SSPs modified the Superpave gradation and volumetric asphalt mixture design requirements to allow easier use of high RAP in asphalt mixtures. The modifications included specifying finer mixtures and mixtures with lower air voids to address durability of these asphalt mixtures containing high RAP contents. • Concerning long-term cracking performance, PennDOT implemented pilot projects to collect asphalt mixture performance test data (Hamburg Wheel Track tests and IDEAL-CT) tests to collect information to support moving to a Balanced Mix Design (BMD) asphalt mixture design approach. • Concerning performance of some longitudinal joints, PennDOT revised its specifications (408/2020-IE) to require sealing/overbanding of all longitudinal joints with PG 64S-22 rather than requiring sealing/overbanding only when the longitudinal joint density is low. We have also done experimental/pilot projects looking at joint sealing alternatives, such as J-Band. • Concerning delaminations, PennDOT revised is Section 460 specification (408/2016-3) to eliminate use of class AET emulsified asphalt for tack coats (min. residue of 28%) and specify use of class TACK emulsified asphalt for tack coates (min. residue of 57%) and to specify use of Non-Tracking Tack, class NTT/CNTT, emulsified asphalt for tack coats to ensure enough tack coat material was applied to pavements. PennDOT also revised the minimum residue application rates for each type of existing pavement. PennDOT also made it a requirement that all existing and newly paved paving courses receive an application of tack coat prior to placing an

asphalt pavement course.
2. Are there ongoing/current issues and challenges that you are facing, and are you planning on making specification changes to address these issues?
➔ Concrete: • The Concrete Paving Quality Improvement (CPQI) committee comprised of Department and Industry members is currently investigating possible joint issues and recommend solutions and possible specification changes. • An internal Concrete Pavement Steering Committee is working on the joint issue as well. ➔ Asphalt: Long-term performance: • PennDOT is continuing with a transition to Balanced Mix Design approach using asphalt mixture performance tests between now and 2025 with goal for full use of BMD by 2025.
Question for District 4: 3. Are there any locally (project specific) approved materials within District 4-0 that are not included in Bulletins 14 and 15?
None that Central Office is aware of currently.

Questions specific to design and construction of asphalt pavements:

1. What are the most common problems that you may have faced during cold weather paving?
Loss of fines at the surface of the asphalt pavement placed during cold weather within the first year after paving.
2. Have you encountered mix segregation/low density in cold weather and if so, what measures have you taken to mitigate the problem?
I believe mix segregation and low density have been encountered in cold weather, but I would not say this is routine. PennDOT implemented revised extended paving season requirements (408/2016-IE) to address cold weather paving in late/extended season paving applications. Contractor must submit an Extended-Season Paving Plan, Form CS-413ES, to address quality control operations in detail, and Form CS-413EQC, Extended-Season Paving Quality Control Documentation, must be submitted daily with all the documentation and measurements associated and outlined in their Extended-Season Paving Plan.
3. Do you require checking the mat temperature in cold paving to ensure there is no thermal segregation?
Monitoring for thermal segregation isn't required. Asphalt mixture delivery temperatures are monitored routinely in the field by PennDOT inspectors. The contractor's technician must obtain mixture temperatures at a minimum on the first three (3) loads and once for every five (5) loads thereafter and document these temperatures on Form CS-413EQC. Time available for compaction is determined daily by the contractor's technician using a software tool such as PaveCool, MultiCool, or another acceptable paving software. A copy of the output from the software must be attached to the daily CS-413EQC.

❖ From PennDOT – District 4

General questions:

1. What have been the recent challenges and concerns regarding design and construction of concrete and asphalt pavements over the last 5 years? Have PennDOT specifications been revised to address these challenges? If not, what prevented a change in the specifications?
➔ Concrete: The issue with mixes containing >25% slag causing "pop outs" in our sidewalk projects. We have lowered the maximum to 25% to assist in these mixes' performance. After many investigations and test results it seems most that all or most issues are finishing related. These mixes set very slowly and that is where the problem lies, we believe. ➔ Asphalt: Asphalt content in our mixes seemed to be an issue. There was basically not enough AC in the superpave mixes to have an adequate longevity of the roadways. We started here by adding 2/10 more AC to our mixes via special provision to assist in this issue.
2. Are there ongoing/current issues and challenges that you are facing, and are you planning on making specification changes to address these issues?
➔ Concrete: I believe we addressed the only issues we had. We have concrete suppliers that supply quality mixes. ➔ Asphalt: Not as of now.
Question for District 4: 3. Are there any locally (project specific) approved materials within District 4-0 that are not included in Bulletins 14 and 15?
No

Questions specific to design and construction of asphalt pavements:

1. What are the most common problems that you may have faced during cold weather paving?
Maintaining temperature of the mixes until it is compacted. I believe we have seen many cases of thermal segregation.
2. Have you encountered mix segregation/low density in cold weather and if so, what measures have you taken to mitigate the problem?
Yes, we try to hold shipping and placing of the material until it's higher than 40 degrees.
3. Do you require checking the mat temperature in cold paving to ensure there is no thermal segregation?
We do, but not sure if it's being followed in the field. I am not a proponent of late season paving as the issues encountered are usually detrimental to the longevity of that road.

❖ From Michigan DOT

General questions:

1. What have been the most recent changes to specifications regarding design and construction of concrete and asphalt pavements? What specific changes have been made?
➔ Concrete: There have not been any significant recent changes in the concrete specifications in the past ten years other than expanding the mandatory use of high-performance concrete from trunkline pavements to also include all structural concrete (excluding prestressed concrete beams.) High-performance concrete, which has been mainstream in Michigan since the early 2000's, includes enhanced freeze-thaw durability properties, optimization of the aggregate blend, reduced total cementitious materials content, and the mandatory inclusion of 25-40 percent SCM replacement of the Portland cement. For concrete pavements, the specifications for curing concrete pavement surfaces was implemented to associate a nominal price reduction for improper curing. Also, the load transfer dowel bar coating specifications were revised from ASTM A775 coating to ASTM A1078 Type 2. ➔ Asphalt: We are in the process of publishing a new spec book effective with jobs let in August. The major change is a reduction of the number of mixes and the gyration levels. Additionally, we are removing seasonal limitations and relying on temperature requirements. Another recent change incorporated monitoring Gse during construction after verifying Gsb during mix design. Previously the Gsb was verified during the initial production lot for that mix.
2. What are the current issues that you are facing, and are you planning on making specification changes to address these issues?
➔ Concrete: Lack of reliable and data-proven durability-based test methodology sufficient to be used as a basis for acceptance. ➔ Asphalt: The changes listed above are addressing our current issues and we will be monitoring the results of implementation to see if additional changes are needed.
3. What are the changes you are considering to be implemented into the next version of your specifications?
➔ Concrete: Possibility Resistivity and the SAM. The specific point in the acceptance process has yet to be determined, based on the reliability of the data, as well as national acceptance amongst concrete producing DOT states. ➔ Asphalt: Please see answers to 1 & 2

Questions specific to design and construction of concrete sidewalks:

1. Do you have a problem with surface scaling of flatwork (sidewalk, pavement, etc.) in your state? How common is this and what types of structures are most affected?
There could be isolated cases of scaling on flatwork that is subjected to extensive handwork during the finishing process. We do not see classic scaling of the surface on our concrete pavements, even with the contractors using 25 percent slag cement in the mixture. However, do not mandate the used of SCMs in sidewalks and curb, so the potential for scaling caused by both hand finishing/over-finishing the surface of a SCM-rich mix is not widespread. Keep in mind that it is very easy for an uninformed finisher to over-finish a SCM-rich mix. Surface defects in flatwork often are a result of poor curing.
2. Is there language within your specifications intended to mitigate scaling?
Proper curing. However, it is pretty common for the contractors to apply the membrane curing compound at a significantly lesser rate than what is required per the specifications for sidewalks and curb-type applications. Curing of pavement slabs is automated and, thus, more easily controlled. Bridge decks require 7 day continuous wet curing with fogging system during concrete placement.
3. Do you prescribe maximum and minimum SCM dosage for concrete? In your experience, does the presence of SCM in concrete increase or reduce the likelihood of scaling?
For trunkline pavements and structural concrete, we require 25-40 percent SCM replacement of the Portland cement. The presence of SCMs in flatwork concrete could promote scaling if the concrete finisher is permitted to over-finish the concrete by treating it as a normal concrete without SCM inclusion and the surface is not properly cured.
4. What is your policy regarding ASR mitigation? Do you follow AASHTO R-80 or do you have your own specification language for ASR mitigation?
Our specifications for ASR mitigation focuses on the fine aggregate to be used in the concrete mixture. We require either preliminary testing of the fine aggregate via ASTM C1293, C1260, or the mitigation method per C1567 using 25-40 percent SCM in the mixture. Test results are valid for two years after completion of the test. We do not directly cite R-80 but used it as a reference when developing our ASR specifications.
5. What forms of deicing chemicals and deicing methods are allowed in your state?
The chemical makeup of the deicers throughout Michigan varies by maintenance garage. The primary materials are CaCl, and NaCl. However, some of our regions use a lot of liquid brine pretreatments (including some agricultural byproducts). These pretreatment products could contain combinations of some of the more aggressive deicing agents.
6. What is the specified slump for construction of sidewalks?
0-3 inches with no admixture, or Type A or D admixture, 0-6 inches with a mid-range admixture.

Questions specific to design and construction of asphalt pavements:

1. What are the most common problems that you may have faced during cold weather paving?
Our specifications limit cold weather paving. Mix segregation, low density, and bonding would be potential issues.
2. Have you encountered mix segregation/low density in cold weather and if so, what measures have you taken to mitigate the problem?
We have a permissive specification for warm mix. We have used insulated trucks when cold weather paving is necessary. In general, our specifications prohibit cold weather paving.
3. Do you require checking the mat temperature in cold paving to ensure there is no thermal segregation?
It is not required.
4. What is the maximum amount of RAP and RAS allowed in asphalt surface mixes?
RAS materials must not contribute more than 17 percent by weight of the total binder content for any HMA mixture. There is not a written limit on RAP but mixes must still meet our volumetric parameters which acts as a limiting factor. Higher traffic volume mixes are limited to 27 percent contribution from RAP/RAS by weight of total binder content.
5. Do you use any performance tests for design of asphalt mixes?
We are not currently using performance tests.

❖ From Minnesota DOT

General questions:

1. What have been the most recent changes to specifications regarding design and construction of concrete and asphalt pavements? What specific changes have been made?
➔ Concrete: MnDOT has made some incremental changes to the concrete pavement mix designs over the last 25 years. This is a link to a report regarding the performance of these mix designs based on maximum w/c ratio, optimized aggregate gradations, pavement smoothness, high quality curing and enhanced aggregate quality with incentives. https://researchprojects.dot.state.mn.us/projectpages/pages/projectDetails.jsf?id=45489&type=DOCUMENT&jftfdi=&jffi=projectDetails%3Fid%3D45489%26type%3DDOCUMENT ➔ Asphalt: Standard design is Superpave. No changes to the standard design however we are currently piloting Superpave5 design. Superpave5 reduces gyrations on mixes that are at 100 and 90 gyrations to 50 gyrations and mixes that are at 60 and 40 gyrations to 30 gyrations. We will pilot Superpave5 at 30 gyrations on the high traffic volume mixes this summer too. Density requirement of 95% of G_{mm} with Superpave5 should help promote long term performance and durability.
2. What are the current issues that you are facing, and are you planning on making specification changes to address these issues?
➔ Concrete: MnDOT is very happy with the quality of our concrete pavements. We have faced some workmanship issues related to dowel bar alignment but have implemented the use of the MIT-Scan T2 to verify steel in plastic concrete and a QC anchoring plan which has addressed many issues. Our other main focus is addressing the availability of fly ash and are looking at the use of reclaimed and bottom ashes as well as review our ASR mitigation requirements which are conservative. ➔ Asphalt: Current issues are low temperature cracking and mixes on the "dryer" side. We have been looking into performance tests and Balanced Mix Design to address cracking and dry mixes.
3. What are the changes you are considering to be implemented into the next version of your specifications?
➔ Concrete: We are currently evaluating the incentive program as well as how to make the concrete mix designs more green "by reducing the total cementitious content". MnDOT is evaluating the Super Air Meter and the Phoenix Device (w/c ratio testing device) ➔ Asphalt: As discussed above, next version of the specification could include a Standard Superpave5 mix design if pilot projects go well. Additionally, could include some performance test requirements or BMD approach.

Questions specific to design and construction of concrete sidewalks:

1. Do you have a problem with surface scaling of flatwork (sidewalk, pavement, etc.) in your state? How common is this and what types of structures are most affected?
Generally speaking we do not see much surface scaling. We occasionally have years where we see mortar flaking from use of harder granite type aggregates. We do not see scaling on concrete pavements unless there is an issue with the timing of curing usually on urban projects that use ready-mix. The highest occurrent of scaling we have seen is in the gutter line on bridge decks and some overall deck scaling.
2. Is there language within your specifications intended to mitigate scaling?
We don't have any specific language related to scaling. For paving we don't allow "blessing of the slab". We have curing specs that have significant monetary adjustments for poor or untimely curing. From sidewalk spec "In accordance with 2521.3E.1.a, "Membrane Curing Method", place the membrane curing compound conforming to 3754, "Poly-Alpha Methyl Styrene (AMS) Membrane Curing Compound," or 3755, "Linseed Oil Membrane Curing Compound," within 30 minutes of concrete placement or once the bleed water has dissipated, unless the Engineer directs otherwise. Place the membrane curing compound on the edges within 30 minutes after permanent removal of the forms or curing blankets, unless the Contract requires otherwise." Failure to properly cure and protect the concrete in accordance with 2521.3E, "Concrete Curing and Protection," will result in the Engineer applying a monetary adjustment in accordance with 1503, "Conformity with Contract Documents," and 1512, "Unacceptable and Unauthorized Work." If the Contract does not contain a separate Contract Item for Structural concrete, the Department will apply a monetary adjustment of $50.00 per cubic yard or 50 percent of the Contractor-provided invoice amount for the concrete in question, whichever is less."
3. Do you prescribe maximum and minimum SCM dosage for concrete? In your experience, does the presence of SCM in concrete increase or reduce the likelihood of scaling?
Maximum percent SCM (Fly Ash/ Slag/Ternary) 33/35/40 – no minimum unless mitigation for ASR is required. Maximum percent SCM (Fly Ash/ Slag/Ternary) 25/30/0 – no minimum for Sidewalks, curb and gutter, slope paving, median Sidewalks, driveway entrances, ADA pedestrian Sidewalks Maximum percent SCM (Fly Ash/ Slag/Ternary) 30/35/0 – no minimum for slip form curb and gutter Maximum percent SCM (Fly Ash/ Slag/Ternary) 30/35/40 – no minimum all other concrete including bridge decks (ASR mitigation may be required for decks)
4. What is your policy regarding ASR mitigation? Do you follow AASHTO R-80 or do you have your own specification language for ASR mitigation?
We have our own specification – currently re-evaluating. For fine and intermediate aggregate we use ASTM C1260 and C1567– MnDOT Modified (don't adjust for gradation)

For coarse aggregate we did ASTM C1293 testing 20 years ago.

Table 2301.2-2
Fine and Intermediate Aggregate ASR Mitigation Requirements

14-day Fine and Intermediate Aggregate Unmitigated Expansion Limits	Class F Fly Ash	Class C Fly Ash	Slag	Ternary (Maximum of 40 percent)			
				Slag/Class F Fly Ash	Slag/Class C Fly Ash	IS(20)/Class F Fly Ash	IS(20)/Class C Fly Ash
≤ 0.150	No mitigation required						
>0.150 –0.200	minimum 20 percent	minimum 20 percent	35 percent	20 percent Slag with a minimum of 15 percent Class F fly ash	20 percent Slag and 20 percent Class C fly ash	Type IS(20) with a minimum of 15 percent Class F	Type IS(20) with a minimum of 15 percent Class C
> 0.200 – 0.300	minimum 20 percent	minimum 30 percent	35 percent				
> 0.300	The Department will reject the fine Aggregate						

Table 2301.2-3
Coarse Aggregate ASR Mitigation Requirements

ASTM C1293 Expansion Results	Class F Fly Ash	Class C Fly Ash	Slag	Slag/Class F Fly Ash	Slag/Class C Fly Ash	IS(20)/Class F Fly Ash	IS(20)/Class C Fly Ash
≤ 0.040	No mitigation required						
>0.040	minimum 30 percent	not allowed	35 percent	20 percent Slag with a minimum of 15 percent Class F fly ash	20 percent Slag and 20 percent Class C fly ash	Type IS(20) with a minimum of 15 percent Class F	Type IS(20) with a minimum of 15 percent Class C

5. What forms of deicing chemicals and deicing methods are allowed in your state?

-

6. What is the specified slump for construction of sidewalks?

Slump is 2 – 5 inches, we are currently in the process of keeping the slump spec but no longer testing for slump in the field – only to be used as needed as a basis for rejection of dry concrete

Questions specific to design and construction of asphalt pavements:

1. What are the most common problems that you may have faced during cold weather paving?
Lower density is one of the most common issues seen during cold weather paving. Another problem is mixture pickup on the pneumatic tired rollers especially when polymer modified binders are used. Tack not breaking.
2. Have you encountered mix segregation/low density in cold weather and if so, what measures have you taken to mitigate the problem?
Minnesota has encountered low density issues related to cold weather paving. The way we try to mitigate the issue is by: 1) Requiring loads be tarped 2) Watch for pick-up on pneumatics tires 3) Pave thicker lifts if possible 4) Watch for inadequate or improper rolling 5) Keeping the mix en-masse by limiting the amount of mix that is windrowed on the grade when using a pick-up machine on the paver. 6) Increasing plant mixing temperatures. 7) Enforcing paving restrictions. 8) Using Pave-Cool software. 9) Having good communication. 10) Requiring the use of paver mounted thermal profiling and using intelligent compaction.
3. Do you require checking the mat temperature in cold paving to ensure there is no thermal segregation?
Most of out projects require the paver be equipped with a paver mounted thermal profiling system which gives a thermal representation of the entire mat. Inspectors also use hand held temperature guns to spot check the temperature of the mat.
4. What is the maximum amount of RAP and RAS allowed in asphalt surface mixes?
RAP and RAS allowances are based on binder replacement requirements. In general terms maximum RAP is about 30% when using a PG xx-28 and RAP is about 20% when using a PG xx-34. Maximum allowable percentage of RAS is 5%.
5. Do you use any performance tests for design of asphalt mixes?
None yet. We have piloted DCT however it does not lend itself to production testing. We are looking into IDEAL CT as an option to DCT. Pilot Superpave designs require Hamburg Wheel. As mentioned above, Minnesota is interested in BMD.

❖ From North Carolina DOT

General questions:

1. What have been the most recent changes to specifications regarding design and construction of concrete and asphalt pavements? What specific changes have been made?
➔ Concrete: No recent changes have been made for Concrete Pavements. ➔ Asphalt: Changes were made in recycled content – limits are now based on Recycled Binder Ratio (%RBR). Previously, all limits were based on percentage of total weight of mix. See Tables 610-4 & 610-5 in the 2018 Specifications: https://connect.ncdot.gov/resources/Specifications/StandSpecLibrary/2018%20Standard%20Specifications%20for%20Roads%20and%20Structures.pdf
2. What are the current issues that you are facing, and are you planning on making specification changes to address these issues?
➔ Concrete: There are no plans for changes in specifications. Any current issues encountered have been project or mix specific and have been dealt with locally. ➔ Asphalt: We are having issues with delamination of asphalt layers. Investigation findings have yet to be specific to one cause. Causes that have been suspect, include: tack coat materials, tack coat application/rate, mix gradation, mix volumetrics (VMA/VFA), and recycle content. Although needed, no specification changes have been identified at this time.
3. What are the changes you are considering to be implemented into the next version of your specifications?
➔ Concrete: No changes are currently being considered. ➔ Asphalt: No changes are currently being considered.

Questions specific to design and construction of concrete sidewalks:

1. Do you have a problem with surface scaling of flatwork (sidewalk, pavement, etc.) in your state? How common is this and what types of structures are most affected?
No specific problems have been documented.
2. Is there language within your specifications intended to mitigate scaling?
No specific language exists in our specifications.
3. Do you prescribe maximum and minimum SCM dosage for concrete? In your experience, does the presence of SCM in concrete increase or reduce the likelihood of scaling?
SCMs are prescribed only for ASR mitigation when known susceptible cement and/or aggregate sources are used. Otherwise, SCMs are optional for mixes that do not require them for ASR mitigation. We have not performed any studies to correlate the use of SCMs with Scaling Resistance.
4. What is your policy regarding ASR mitigation? Do you follow AASHTO R-80 or do you have your own specification language for ASR mitigation?
SCMs are required for ASR mitigation in mixes that contain cement with Alkali content between 0.6 to 1.0% and for mixes using a reactive aggregate. See specifics in Section 1024-1 of our specifications: https://connect.ncdot.gov/resources/Specifications/StandSpecLibrary/2018%20Standard%20Specifications%20for%20Roads%20and%20Structures.pdf
5. What forms of deicing chemicals and deicing methods are allowed in your state?
Brine and Salt+Sand Our Brine solution has been very successful for us - water and 23 percent salt. It is used to pretreat roadways in dry conditions with temperatures above 18 degrees.
6. What is the specified slump for construction of sidewalks?
Class B concrete is generally used for construction of sidewalks. Specifications require Class B to meet the following requirements, depending on placement method: - Machine-placed: 1.5” max - Hand-placed: 2.5” max - Non-vibrated: 4.0” max

Questions specific to design and construction of asphalt pavements:

1. What are the most common problems that you may have faced during cold weather paving?

Segregation and possibly delamination – I say “possibly” because delamination has not been proven to be a symptom of cold-weather paving.

We have also begun seeing separation of longitudinal joints, but that has yet to be attributed specifically to cold-weather paving.

2. Have you encountered mix segregation/low density in cold weather and if so, what measures have you taken to mitigate the problem?

Yes.

Normally, paving operations are controlled by Air/Surface temperatures and the mix type being placed – see Table 610-6 of our specifications:
https://connect.ncdot.gov/resources/Specifications/StandSpecLibrary/2018%20Standard%20Specifications%20for%20Roads%20and%20Structures.pdf

Also, we have seasonal limitations in place for the final lift of surface mix:

- Lifts >1”: December 15 – March 16
- Lifts <1”: November 15 – April 1

Additional limitations are in effect for mixes using PG76-22 binder and for mixes that use recycled asphalt shingles.

3. Do you require checking the mat temperature in cold paving to ensure there is no thermal segregation?

No.

Air and Surface temperatures must meet Table 610-6. Plus, mix temperatures are checked for every truckload.

4. What is the maximum amount of RAP and RAS allowed in asphalt surface mixes?

Limits are based on %RBR and the PG Binder grade used.

See Tables 610-4 & 610-5 in the 2018 Specifications:
https://connect.ncdot.gov/resources/Specifications/StandSpecLibrary/2018%20Standard%20Specifications%20for%20Roads%20and%20Structures.pdf

5. Do you use any performance tests for design of asphalt mixes?

Yes.

APA Rut testing is required for ALL dense-graded surface mix designs.

Tensile Strength Ratio (TSR) testing is required for all dense-graded mix designs submitted and within the first 7 days of production for all job-mix formulas produced.

❖ From Texas DOT

General questions:

1. What have been the most recent changes to specifications regarding design and construction of concrete and asphalt pavements? What specific changes have been made?
➔ Concrete: The minimum replacement of Class F fly ash for ASR mitigation has been changed from a 20% for all sources to varying minimums per each individual source. Allow Type IL cements in all classes of concrete. Allow automated slump monitoring systems. CRCP standard was changed to remove allowance for reduction of steel content if low CTE concrete was used. ➔ Asphalt: Modified our Superpave gradations to promote more asphalt and better stone-on-stone structure. No grade dumping from a polymer modified to a non-polymer modified binder for surface mixtures. Lowered the allowable recycled material in surface mixtures and lowered the use of RAS in subsurface layers. Treat WMA the same as HMA. In the past we allowed additional recycle and modified performance tests temperatures. Modified the maximum allowable production temperatures based on binder grade. Ignition oven correction factors cannot be more than 12 months old. Sand equivalent is now performed on individual fine aggregates as opposed to the combined gradation. Allowable roadway and air temperatures for paving modified. Added a minimum allowable mixture temperature entering the paver Tack is now a separate pay item. We have also added an informational shear test to test for bonding.
2. What are the current issues that you are facing, and are you planning on making specification changes to address these issues?
➔ Concrete: Seasonal fly ash supply issues creating delays. There is currently is an allowance for strength cement mix design as an alternative. Mid-depth horizontal delamination in thick CRCP sections. Ongoing research to evaluate location for reinforcing steel in pavement. ➔ Asphalt: Dry mixtures/cracking, bonding issues, localized stripping issues. All of the aforementioned changes were to help with these issues.
3. What are the changes you are considering to be implemented into the next version of your specifications?
➔ Concrete: No major changes to the concrete pavement construction specification. Concrete Spec.: incorporate natural pozzolans, allow lab scale trial batches, allow e-

ticketing, testing from point of truck discharge rather than point of placement

➔ Asphalt:
We have just overhauled all of our HMA specs. We plan to monitor these changes and the changes in performance. Based on the results, we will adjust accordingly. No major changes planned currently.

Questions specific to design and construction of concrete sidewalks:

1. Do you have a problem with surface scaling of flatwork (sidewalk, pavement, etc.) in your state? How common is this and what types of structures are most affected?
Not aware of any scaling issues.
2. Is there language within your specifications intended to mitigate scaling?
No.
3. Do you prescribe maximum and minimum SCM dosage for concrete? In your experience, does the presence of SCM in concrete increase or reduce the likelihood of scaling?
Yes. N/A
4. What is your policy regarding ASR mitigation? Do you follow AASHTO R-80 or do you have your own specification language for ASR mitigation?
All aggregates are reactive and a mitigation strategy must be used. We have 8 mix design option for ASR mitigation (SCM, limit alkali loading, etc). We do not use AASHTO R80.
5. What forms of deicing chemicals and deicing methods are allowed in your state?
See link for De-icer specification. Primarily road salt is used for brine application. https://ftp.txdot.gov/pub/txdot-info/cst/DMS/6000_series/pdfs/6400.pdf
6. What is the specified slump for construction of sidewalks?
No slump specification for sidewalk concrete. Strength is the only specification requirement for this class of concrete.

Questions specific to design and construction of asphalt pavements:

1. What are the most common problems that you may have faced during cold weather paving?

Thermal segregation. Physical segregation due to material excessively cooling during paving. Low in-place densities.

2. Have you encountered mix segregation/low density in cold weather and if so, what measures have you taken to mitigate the problem?

Yes. Our specifications have language for minimum pavement temperatures, minimum air temperatures, forecasted temperature trends, mix delivery temperatures. Our specification also strongly encourages the use of WMA additives and thermal imaging equipment during colder paving.

3. Do you require checking the mat temperature in cold paving to ensure there is no thermal segregation?

Yes. We use Tex-244-F to check for thermal segregation. Our specification also strongly incentivizes the contractor to use a thermal imaging system on their paver.

4. What is the maximum amount of RAP and RAS allowed in asphalt surface mixes?

This is specification dependent. For Superpave mixtures: No RAS in the surface. RAP is outlined in the 2 tables below.

Table 4
Maximum Allowable Amounts of RAP[1]

Maximum Allowable Fractionated RAP (%)		
Surface	Intermediate	Base
20.0	30.0	35.0

1. Must also meet the recycled binder to total binder ratio shown in Table 5.

Table 5
Allowable Substitute PG Binders and Maximum Recycled Binder Ratios

Originally Specified PG Binder	Allowable Substitute PG Binder for Surface Mixes	Allowable Substitute PG Binder for Intermediate and Base Mixes	Maximum Ratio of Recycled Binder[1] to Total Binder (%)		
			Surface	Intermediate	Base
76-22[4,5]	70-22	70-22	15.0	25.0	30.0
70-22[2,5]	N/A	64-22	15.0	25.0	30.0
64-22[2,3]	N/A	N/A	15.0	25.0	30.0
76-28[4,5]	70-28	70-28	15.0	25.0	30.0
70-28[2,5]	N/A	64-28	15.0	25.0	30.0
64-28[2,3]	N/A	N/A	15.0	25.0	30.0

1. Combined recycled binder from RAP and RAS. RAS is not permitted in surface mixtures unless otherwise shown on the plans.
2. Binder substitution is not allowed for surface mixtures.
3. Binder substitution is not allowed for intermediate and base mixtures.
4. Use no more than 15.0% recycled binder in surface mixtures when using this originally specified PG binder.
5. Use no more than 25.0% recycled binder when using this originally specified PG binder for intermediate mixtures. Use no more than 30.0% recycled binder when using this originally specified PG binder for base mixtures.

5. Do you use any performance tests for design of asphalt mixes and if so could you explain which performance tests are used?
Yes. Different specifications rely on different tests. For most mixtures we use, we do require IDT and Hamburg testing. Some mixtures such as PFC (OGFC) relies on the Cantabro to prevent raveling. Some of our mixtures also rely on a cracking test such as the Texas Overlay Test. Currently, we are also performing informational Shear Bond Testing to test for tack strength.

❖ From Virginia DOT

General questions:

1. What have been the most recent changes to specifications regarding design and construction of concrete and asphalt pavements? What specific changes have been made?
➔ Concrete: In regards to concrete pavements, there haven't been many changes to the specifications lately. ➔ Asphalt: We used to have asphalt bonus and density bonus for maintenance projects under Special Provision (SP). From 2021, we moved density bonus to Spec which means it applies to maintenance and construction projects since we have seen positive effects.
2. What are the current issues that you are facing, and are you planning on making specification changes to address these issues?
➔ Concrete: One of the biggest issues we are currently facing is our concrete patching and its performance. ➔ Asphalt: Just need to improve performance (extend lift cycle). We have been trying to do a lot of research on Balanced Mix Design (BMD) and pilot projects. We are targeting the initial implementation on 2023 paving season with some of surface mixes.
3. What are the changes you are considering to be implemented into the next version of your specifications?
➔ Concrete: We are looking into updating our concrete patching special provision to include more mix requirements and placement requirements. ➔ Asphalt: BMD initiative is the biggest task under Asphalt program. We are considering BMD testing in Design as well as in Production.

Questions specific to design and construction of concrete sidewalks:

1. Do you have a problem with surface scaling of flatwork (sidewalk, pavement, etc.) in your state? How common is this and what types of structures are most affected?
We have had problems with it. Mainly on bridge decks, sidewalks and pavement.
2. Is there language within your specifications intended to mitigate scaling?
We don't have language that specifically calls out scaling but we do require structures subject to freeze/thaw to be air entrained. We specify proper curing methods.
3. Do you prescribe maximum and minimum SCM dosage for concrete? In your experience, does the presence of SCM in concrete increase or reduce the likelihood of scaling?
Yes our specification has minimum SCM dosages.

Mineral Admixtures	Total Alkalies of Cement is less than or equal to 0.75%	Total Alkalies of Cement is greater than 0.75% and less than or equal to 1.0%
Class F Flyash	20%	25%
GGBF Slag	40%	50%
Silica Fume	7%	10%
Metakaolin	7%	10%

4. What is your policy regarding ASR mitigation? Do you follow AASHTO R-80 or do you have your own specification language for ASR mitigation?
We have our own specification language for ASR mitigation. We require minimum SCM based on alkali content of the cementitious material
5. What forms of deicing chemicals and deicing methods are allowed in your state?
Sodium Chloride, brine made up of Calcium Chloride & Sodium Chloride.
6. What is the specified slump for construction of sidewalks?
We require A3 concrete to be used. The slump of that is 1-5 inches.

Questions specific to design and construction of asphalt pavements:

1. What are the most common problems that you may have faced during cold weather paving?
We are limiting temp and most of maintenance paving will be done by mod-Nov. Some of thinner mixes (and polymer mixes) need to be hotter.
2. Have you encountered mix segregation/low density in cold weather and if so, what measures have you taken to mitigate the problem?
Not a lot of physical segregation reported. Hotter temp for thinner mix is also related to density (and workability). We don't specify about measuring physical segregation. For density, we have density bonus spec (up to 5%) helping a lot to eliminate lower density recently.
3. Do you require checking the mat temperature in cold paving to ensure there is no thermal segregation?
We are checking for placement temp/compaction temp (spot check), but not for thermal segregation.
4. What is the maximum amount of RAP and RAS allowed in asphalt surface mixes?
RAP 30%, RAS 5%
5. Do you use any performance tests for design of asphalt mixes?
Only TSR for the first production. However, we have done BMD pilot projects for a couple of years and will do initial implementation 2023 with IDT-CT, APA, and Cantabro tests.

❖ From Wisconsin DOT

Questions specific to design and construction of concrete sidewalks:

1. Do you have a problem with surface scaling of flatwork (sidewalk, pavement, etc.) in your state? How common is this and what types of structures are most affected?
Generally no. Our flatwork is cured just like our pavement, and I believe this helps prevent most scaling issues. If we see any scaling, it is most likely on concrete where snow and salt are piled and remain thru most of the winter.
2. Is there language within your specifications intended to mitigate scaling?
We limit the amount of chert, lightweight and deleterious pieces in our aggregates. We also require all concrete is cured. After that, our specification allows us 5 years to file a claim against a contractor for workmanship defects.
3. Do you prescribe maximum and minimum SCM dosage for concrete? In your experience, does the presence of SCM in concrete increase or reduce the likelihood of scaling?
Our current specification requires SCM usage in structural concrete. We have a permissive spec for 0-30% cement replacement with SCM's in all other mixes. In 2022, we are moving the range to 15-30% to require the use of SCM's in all concrete.
4. What is your policy regarding ASR mitigation? Do you follow AASHTO R-80 or do you have your own specification language for ASR mitigation?
501.2.5.4.4 Alkali Silica Reactivity Testing and Mitigation Requirements (1) If using coarse aggregate from sources containing significant amounts of fine-grained granitic rocks including felsic-volcanics, felsic-metavolcanics, rhyolite, diorite, gneiss, or quartzite; test coarse aggregate according to ASTM C1260 for alkali silica reactivity. Gravel aggregates are exempt from this requirement. (2) If ASTM C1260 tests indicate a 14-day expansion of 0.15 percent or greater, perform additional testing according to ASTM C1567. Test mortar bars made with coarse aggregate and the blend of cementitious materials proposed for concrete placed under the contract. The department will reject the aggregate if ASTM C1567 tests confirm mortar bar expansion of 0.15 percent or greater at 14 days. 21 Spec - 501 Concrete (wisconsindot.gov)
5. What forms of deicing chemicals and deicing methods are allowed in your state?
We use prewetting of salts, we will make brines and pretreat roads. Winter maintenance is provided by our 72 counties, and their guide is found here. DTSD Highway Maintenance - WinterBestPractices (sharepoint.com)
6. What is the specified slump for construction of sidewalks?
1-4 inches for formed concrete.

Questions specific to design and construction of asphalt pavements:

1. What are the most common problems that you may have faced during cold weather paving?
Inconsistent compaction and long term performance.
2. Have you encountered mix segregation/low density in cold weather and if so, what measures have you taken to mitigate the problem?
Yes. We have developed a cold weather spec requiring warm mix additive and additional compactive rollers. We do not allow paving on frozen grade or below 32F for lower layers or 36F for upper layers. Our use of a PWL specification that has a bonus for density also incentivizes better paving practices.
3. Do you require checking the mat temperature in cold paving to ensure there is no thermal segregation?
We do not.
4. What is the maximum amount of RAP and RAS allowed in asphalt surface mixes?
We allow up to 25% binder replacement in our surface mixes.
5. Do you use any performance tests for design of asphalt mixes?
Not by specification, but we are working on cracking and rutting specs.