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Implementing the Superpave 5 Asphalt Mixture Design Method in Indiana

**John E. Haddock, Reyhaneh Rahbar-Rastegar,
M. Reza Pouranian, Miguel Montoya, Harsh Patel**

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AUTHORS

John E. Haddock
Professor of Civil Engineering
Director of the Indiana Local Technical Assistance Program
Lyles School of Civil Engineering
Purdue University
(765) 496-3996
jhaddock@purdue.edu
Corresponding Author

Reyhaneh Rahbar-Rastegar
Research Engineer
Lyles School of Civil Engineering
Purdue University

M. Reza Pouranian
Miguel Montoya
Harsh Patel
Graduate Research Assistants
Lyles School of Civil Engineering
Purdue University

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16. Abstract

Recent research developments have indicated that asphalt mixture durability and pavement life can be increased by modifying the Superpave asphalt mixture design method to achieve an in-place density of 95%, approximately 2% higher than the density requirements of conventionally designed Superpave mixtures. Doing so requires increasing the design air voids content to 5% and making changes to the mixture aggregate gradation so that effective binder content is not lowered. After successful laboratory testing of this modified mixture design method, known as Superpave 5, two controlled field trials and one full scale demonstration project, the Indiana Department of Transportation (INDOT) let 12 trial projects across the six INDOT districts based on the design method. The Purdue University research team was tasked with observing the implementation of the Superpave 5 mixture design method, documenting the construction and completing an in-depth analysis of the quality control and quality assurance (QC/QA) data obtained from the projects.

QC and QA data for each construction project were examined using various statistical metrics to determine construction performance with respect to INDOT Superpave 5 specifications. The data indicate that, on average, the contractors achieved 5% laboratory air voids, which coincides with the Superpave 5 recommendation of 5%. However, on average, the as-constructed mat density of 93.8% is roughly 1% less than the INDOT Superpave 5 specification. It is recommended that INDOT monitor performance of the Superpave 5 mixtures and implement some type of additional training for contractor personnel, in order to help them increase their understanding of Superpave 5 concepts and how best to implement the design method in their operation.

17. Key Words
superpave, asphalt mixture design, asphalt pavement density

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EXECUTIVE SUMMARY

Introduction

Recent research developments have indicated that asphalt mixture durability and pavement life can be increased by modifying the Superpave asphalt mixture design method to achieve in-place densities of 95%—approximately 2% higher than the density requirements of conventionally designed Superpave mixtures. Doing so involves increasing the design air voids content to 5% and making changes to the mixture aggregate gradation so that effective binder content is not lowered. After successful laboratory testing, two controlled field trials, and one full-scale demonstration project of this modified mixture design method, known as Superpave 5, the Indiana Department of Transportation (INDOT) initiated 12 trial projects, one in each of the six INDOT districts, based on the design method. The Purdue University research team was tasked with observing the implementation of the Superpave 5 mixture design method; documenting the construction; completing an in-depth analysis of the quality control and quality assurance (QC/QA) data obtained from the projects; completing a literature review concerning asphalt mixture lift thickness and its effect on asphalt pavement density; and making recommendations based on the lift thicknesses used by INDOT.

The research team visited five Superpave 5 construction sites, observed the construction process, and garnered feedback from the field engineers and contractor personnel about the modified mixture design procedure and any construction concerns. QC and QA data for the projects were supplied to the research team for each of the nine projects. Each set of project data was analyzed individually, then all the data was combined and analyzed in its entirety. Laboratory air voids content and field density data were compared to the Superpave 5 recommendations.

Findings

- It is possible to achieve 5% laboratory air voids content during asphalt mixture production when the mixture has been designed at 5% air voids content.
- Overall, the Superpave 5 mixtures were slightly under-compacted with respect to Superpave 5 recommendations, despite previous trial projects having established that 95% density could be achieved without additional compaction effort beyond that used for conventional Superpave mixtures.
- Given that mat densities for the project were lower than anticipated, we concluded that some additional training is needed for the contractors in order to help them better design Superpave 5 mixtures that can be field compacted to the 95% target density.
- The study findings also revealed what appears to be a possible bias in the QC and QA data. In looking at data distributions, the QC data often appear to have lower laboratory air voids contents and higher as-constructed mat densities than the project QA data.

Implementation

While the as-constructed mat densities from the nine projects were lower than expected for Superpave 5 mixtures, they were perhaps slightly higher than typical construction densities for conventional Superpave mixtures. It is recommended that field performance of the Superpave 5 mixtures from these projects be monitored over time to examine the impact of the Superpave 5 mixture design method.

Some type of additional training for contractor personnel is recommended. The aim of such training should be to increase their understanding of Superpave 5 concepts and how best to implement the design method in their operation.

Finally, it is recommended that INDOT do a small study to investigate the as-built lift thicknesses of asphalt pavement layers. This data should be collected and examined for compliance with the lift thickness recommendation to ensure the any under-compaction issues are not the result of inadequate lift thickness.

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1. INTRODUCTION

Density, both short- and long-term, is one of the most important factors in determining asphalt pavement performance. Linden et al. (1989) demonstrated that each 1% increase in the air voids content (1% decrease in density) of an asphalt pavement can result in a 10% loss in pavement life. Currently, the Indiana Department of Transportation's (INDOT) method of asphalt mixture design and construction of asphalt pavements targets 4% air voids content (V_a) in the laboratory compacted specimens, as required by the conventional Superpave mixture design method. Motivated to increase in-place asphalt pavement densities, Hekmatfar et al. (2015) successfully modified the standard Superpave asphalt mixture design method to allow contractors to achieve higher in-place density without increasing compaction effort. Known colloquially as "Superpave 5," this modified method selects the optimum binder content based on 5% laboratory air voids content, rather than at 4%, as does the standard method. Additionally, the number of design gyrations (N_{design}) needed to compact laboratory specimens are lowered in the Superpave 5 method. Finally, the required voids in the mineral aggregate (VMA) is raised by 1%, to account for the 1% higher air voids content and maintain the effective binder content (P_{be}). In the controlled study done by Hekmatfar et al. (2015), it was noted that the Superpave 5 mixture design method produced mixtures that could be compacted to 5% air voids (95% density) in the field without requiring additional compaction effort beyond that used for the standard mixtures.

The Superpave 5 mixture design method was successfully tested in the laboratory, two controlled field tests and one full-scale demonstration project (Montoya et al., 2018; Montoya & Haddock, 2019). As a result, INDOT let 12 additional projects (two each in of the six INDOT districts) based on the updated specification that included the Superpave 5 mixture design method. As part of these projects, INDOT contracted with Purdue University to observe the construction of at least one project in each district, document the construction and analyze the resulting data from all 12 projects.

Given the contract with INDOT, the objectives of this research were twofold. Firstly, analyze the construction data to determine if the specifications were met and if any additional adjustments are needed to the Superpave 5 mixture design method. Secondly, INDOT specifically asked that a literature review be completed concerning asphalt mixture lift thickness and its effect on asphalt pavement density, and recommendations made on the lift thicknesses used by INDOT.

2. LITERATURE REVIEW

2.1 Asphalt Mixture Design

Asphalt is one the most widely used construction materials throughout the world with 94% of the 2.7 million miles of United States (US) paved roads and highways being surfaced with some type of asphalt product (NAPA, n.d.). Asphalt mixture design plays a crucial role in ensuring the best mechanical behavior and durability of these asphalt pavements as the behavior of the asphalt mixtures is affected by the properties of individual components and their interaction in the system (McGennis, 1995).

The Marshall asphalt mixture design method has been widely used throughout the world since its development in the 1940's (Kandhal & Koehler, 1985). The Marshall design method involves choosing an aggregate gradation and a compaction level, then making trial specimens to determine the optimum binder content for the chosen gradation. In most scenarios, the optimum binder content is chosen such that the mixture has 4% air voids content when appropriately compacted in the laboratory (Asphalt Institute, 2014). Air voids are small pockets of air that occur between the asphalt-coated aggregated particles in the final compacted mixture. Air voids are critical to constructed asphalt pavements as they allow some additional compaction under traffic (post-construction) and provide adequate space for asphalt to expand with rising temperatures. In this study, laboratory air voids contents were determined according to the Association of American Highway and Transportation Officials (AASHTO) standard method, T269, *Percent Air Voids in Compacted Dense and Open Asphalt Mixtures*, using the equation, $V_a = \left(\left[1 - \left(\frac{G_{mb}}{G_{mb}}\right)\right] * 100\right)$, where G_{mm} is the maximum theoretical specific gravity of the mixture and G_{mb} is the bulk specific gravity of the mixture.

Despite the Marshall mixture design method's popularity, it has been argued the method is empirical and therefore not entirely able to incorporate the full effects of variable environmental and loading conditions (Asi, 2007). The method does not incorporate the effects of component types and properties on the resulting pavement performance (Asi, 2007; Jitsangiam et al., 2013). It has also been noted that the Marshall laboratory compaction method (impact hammer) does not satisfactorily produce the densities observed in the field (Roberts et al., 2002). According to a study conducted in Thailand, continued use of the Marshall mixture design method for asphalt mixture design was believed to be responsible for premature pavement deterioration (Jitsangiam et al., 2013).

Over the years, due to a poor understanding of failure mechanisms, the success of the Marshall mixture design method was mainly attributed to thick, uneconomical pavement sections (Swami et al., 2004). Concerns about the Marshall mixture design method lead to the development of a new asphalt mixture design method in the US that incorporates performance-based asphalt binder specifications. Started in the 1980s, the Strategic Highway Research Program (SHRP), lead to the development of the Superpave (SUperior PERforming PAVEments) mixture design system (Brown et al., 2001; Roberts et al., 2002). The Superpave asphalt mixture design system consists of aggregate tests and criteria, and the utilization of volumetrics based on specimens compacted in the Superpave gyratory compactor (SGC), the SGC having been developed as part of the SHRP work (Asi, 2007; Jitsangiam et al., 2013; Roberts et al., 2002).

With the Superpave mixture design method, optimum binder content is determined at 4% laboratory air voids content (design air voids) and in-place, as-constructed air voids contents are expected to be around 7% to 8% (Hekmatfar et al., 2015; Jitsangiam et al., 2013). The method uses 6-in. diameter SGC-compacted specimens to evaluate the volumetric properties of a mixture (Anderson, 1993), as the SGC can produce laboratory specimens whose volumetric and engineering properties are sufficiently close to those of field specimens (Asi, 2007; Jitsangiam et al., 2013; Sousa et al., 1991). The Superpave mixture design method is thought to have enhanced asphalt mixture performance under severe conditions such as temperature fluctuations and variable environments (Jitsangiam et al., 2013; Roberts et al., 2002).

Currently, INDOT uses the Superpave mixture design method to design asphalt mixtures targeting 4% air voids content at optimum binder content in laboratory compacted specimens and 93% in-place (7% air voids content) density in field compacted mixtures (INDOT, 2018). Density is technically defined as the weight of the material that occupies a unit volume of space. The present study uses percent density of the as-constructed pavement as the physical measurement of density, expressed as a percentage of G_{mm} (Aschenbrener et al., 2017). However, even when the in-place density criterion is statistically met, it can result in lower than desired density in 10% of the pavement area. This can lead to decreased pavement service life due to premature asphalt aging and thereby durability loss (Hekmatfar et al., 2015). The literature indicates that increasing the pavement density can significantly increase pavement durability by substantially decreasing pavement aging. Huber et al. (in press) showed that a lower air void reduces the air permeability to the asphalt pavement, resulting in less aging. A higher durability and better cracking performance are expected to be observed for less aged asphalt mixtures.

Hekmatfar et al. (2015) conducted a study exploring the possibility of increasing initial asphalt pavement density by altering the Superpave mixture design method. By changing the design air voids content from 4%–5%, they demonstrated that initial in-place densities of 95% could be achieved, in contrast to the common 92%–93%, without increasing the compaction effort. Thus, a slight change in the mixture design method increased asphalt pavement durability.

2.2 Compaction and Lift Thickness

Compaction of asphalt mixtures is defined as the process by which the amount of air voids is reduced in a mixture through application of external forces, hence reorienting the particles into a denser arrangement. The degree of asphalt mixture compaction in a constructed pavement is one of the most important factors for ensuring asphalt pavement quality and durability (Aschenbrener et al., 2017; Tran et al., 2016). It is been suggested that approximately 10% of the pavement life is lost with a 1% increase in air voids (1% loss in density) (Linden, 1989). Additionally, according to Finn and Epps (1980), laboratory investigations suggest that asphalt mixture fatigue life can be reduced by 35% or more for every 1% increase in air voids.

There are various compaction techniques available to achieve the desired density in asphalt mixtures, both in the field and the laboratory. Previous studies have discussed numerous factors affecting the compactibility of asphalt mixtures and thus the constructed pavement. These are lift thickness, nominal maximum aggregate size (NMAS), aggregate gradation of the mixture and design compactive effort (Asphalt Magazine, 2014; Cooley et al., 2002). Among these, many researchers have noted that lift thickness can perhaps have the most significant influence on density and hence the degree of compaction in the pavement (Hainin et al., 2013; Musselman et al., 1998). Lift thickness is defined as the thickness of compacted asphalt layers or “lifts,” which are placed one over another to construct an asphalt pavement. The literature reports that lift thickness has a direct correlation to the compaction process during pavement construction, thereby affecting the final air-voids ratio of the completed pavement (Brown et al., 2004).

Hainin et al. (2013) evaluated 14 asphalt mixtures for lift thickness and permeability relationships. They concluded the heat retained in a mixture increases proportionately with the thickness of the layer being placed. This ultimately leads to an increase in the workability and compactibility of a mixture. Cooley, Brown, and Maghsoodloo (2001) studied in-place critical field permeability and pavement density values for coarse-graded Superpave pavements. They used the data to recommend permeability values and critical in-place densities for the Superpave-designed mixtures. In-place permeability was measured using a special device developed by Cooley and Brown (2000) which could be used in the field. Their research concluded that permeability characteristics of the asphalt pavement is greatly affected by the asphalt mixture NMAS. They also stated that thinner pavements are likely to be more permeable.

Brown et al. (2004) investigated the minimum ratio of lift thickness (t) to NMAS (t/NMAS) needed for desirable pavement density levels to be achievable and assessed the relationship between in-place air voids, lift thickness and permeability. It was found the relationship between lift thickness and air voids is essentially one of compactibility. If the lift thickness is too thin, asphalt mixture will not be sufficiently available during compaction and hence, the aggregate particles cannot slide past each other. Thinner lifts also tend to cool quickly, thereby making them harder to compact. Musselman et al. (1998) investigated Florida’s early

Superpave mixture design method implementation experience. They established that lift thickness should ideally be four times the NMAS for coarse-graded Superpave mixtures. Their suggestions for coarse-graded Superpave mixture lift thicknesses were 1.5 in. for a 3/8-in. mixture, 2.0 in. for a 1/2-in. mixture, and 3.0 in. for a 3/4-in. mixture.

In discussing Federal Aviation Administration (FAA) asphalt specifications, the Washington Asphalt Pavement Association (WAPA, 2016) gave various recommendations for the minimum lift thickness required for asphalt pavement construction. Their determination was that minimum lift thickness should be between three to four times NMAS. Moreover, the association advises that maximum lift thickness should be less than six times NMAS to achieve desirable compaction. Scherocman and Walker (2020) also discussed various factors contributing to asphalt compaction. Properties of the asphalt mixture, type and density of the underlying base course material, thickness of the asphalt layers and the environmental conditions at the time of asphalt placement were cited as the most important factors in achieving density. It was stressed that thick lifts have higher compactibility than the thinner lifts, as thicker lifts increase the heat retention, ultimately leading to improved compaction. Concurring with the Musselman et al. (1998) findings, Scherocman and Walker also state that minimum lift thickness should be more than three times the NMAS for fine-graded mixtures. Similarly, for coarse-graded mixtures, the lift thickness should be four times the NMAS (Scherocman & Walker, 2020).

3. PROJECT OVERVIEW

A total of 12 projects, two in each of the six INDOT districts, were let to contracts by INDOT requiring the asphalt mixtures to be designed using the Superpave 5 mixture design method and constructed using the attendant pavement density specification. One of the projects was mistakenly completed as a standard Superpave mixture, leaving only 11 projects in the experiment. The one remaining Superpave 5 project in the LaPorte District was completed early in the 2018 paving season, before the research team could visit the project. Additionally, two of the projects were not completed during the 2018 paving season. Thus, of the original 12 projects, the research team visited only five project sites and only 9 projects were completed in 2018. This report therefore contains data from 9 of the 12 projects. Table 3.1 provides information about the 11 projects and shows which projects are included in the report. The shaded projects are those visited by the research team. As seen in the table, most of the projects were overlays, with only three being pavement replacement projects. Figure 3.1 indicates the approximate location of each project.

As part of the construction site visits, the research team interacted with contractor and INDOT personnel, made and recorded observations, sampled materials, and arranged to obtain the project quality control and quality assurance (QC/QA) data. Figure 3.2 shows photographs taken from the six site visits. Once the data was obtained, it was then analyzed for compliance with the Superpave 5 specifications.

TABLE 3.1
Superpave 5 project information

	Route	From	To	Work Type	Analysed in the Current Report?
LaPorte	SR 23	SR 10	SR 8	Asphalt mixture overlay, preventive maintenance	Yes
Fort Wayne	US 20	0.07 mi E of SR 127	0.58 mi E of SR 127	Pavement replacement	No
	US 30	**0.13 mi W of SR 13**	**0.06 mi E of SR 5**	**Asphalt mixture overlay, minor structural**	**Yes**
Crawfordsville	SR 75	3.21 mi N of I-74	3.99 mi N of I-74	Pavement replacement	No
	US 231	**1.38 mi S of SR 32 S Jct**	**0.29 mi N of US 136**	**Asphalt mixture overlay, preventive maintenance**	**Yes**
Greenfield	SR 135	0.52 mi S of US 31	US 31	Pavement replacement	Yes
	US 31	**1.55 mi S I-465**	**0.39 mi N I-465**	**Asphalt mixture overlay, minor structural**	**Yes**
Seymour	**US 231**	**E jct of SR 46**	**SR 46**	**Asphalt mixture overlay, preventive maintenance**	**Yes**
	US 50	SR 350	SR 1	Asphalt mixture overlay, preventive maintenance	Yes
Vincennes	US 150	0.18 mi W of E Jct of SR 56	SR 66	Asphalt mixture overlay minor structural	Yes
	SR 62	**1.96 mi E of W Jct of SR-69**	**1.34 mi W of E jct SR-69**	**Asphalt mixture overlay, minor structural**	**Yes**

Note: Projects in **bold text** are those visited by the research team.

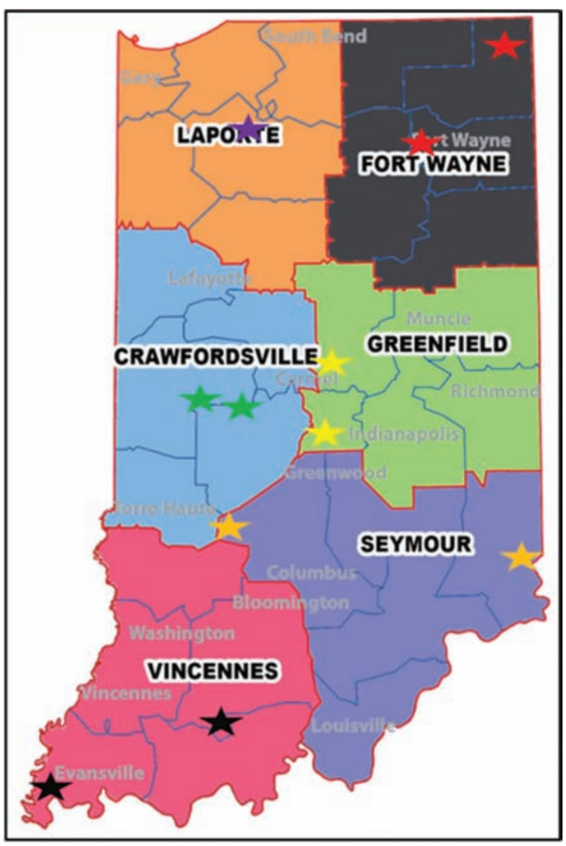
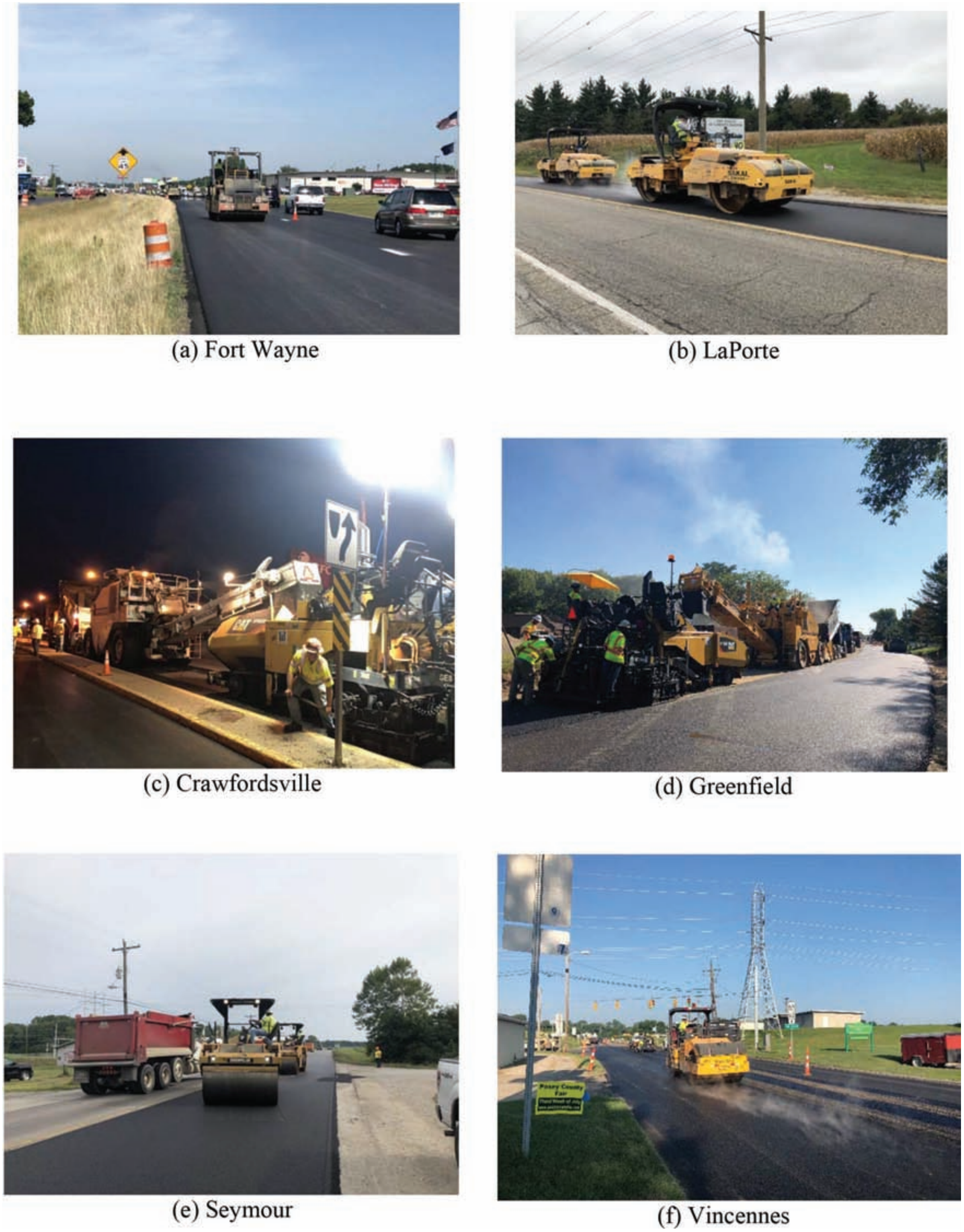


Figure 3.1 Superpave 5 project locations.



(a) Fort Wayne (b) LaPorte

(c) Crawfordsville (d) Greenfield

(e) Seymour (f) Vincennes

Figure 3.2 Photographs from construction site visits.

4. DATA ANALYSIS AND DISCUSSION

The QC/QA data from each of the nine completed projects were analyzed. These data are generated from asphalt mixture plate and core samples extracted from the roadway. Figure 4.1 shows the plate sampling in process. This process was completed according to INDOT standard methods and provided the asphalt mixture used to determine laboratory air voids contents. Once a constructed pavement lift had sufficiently cooled, cores were taken in accordance with INDOT standard procedures. All QC/QA work was completed by the contractor or INDOT personnel, not by the research team. The asphalt mixture properties obtained

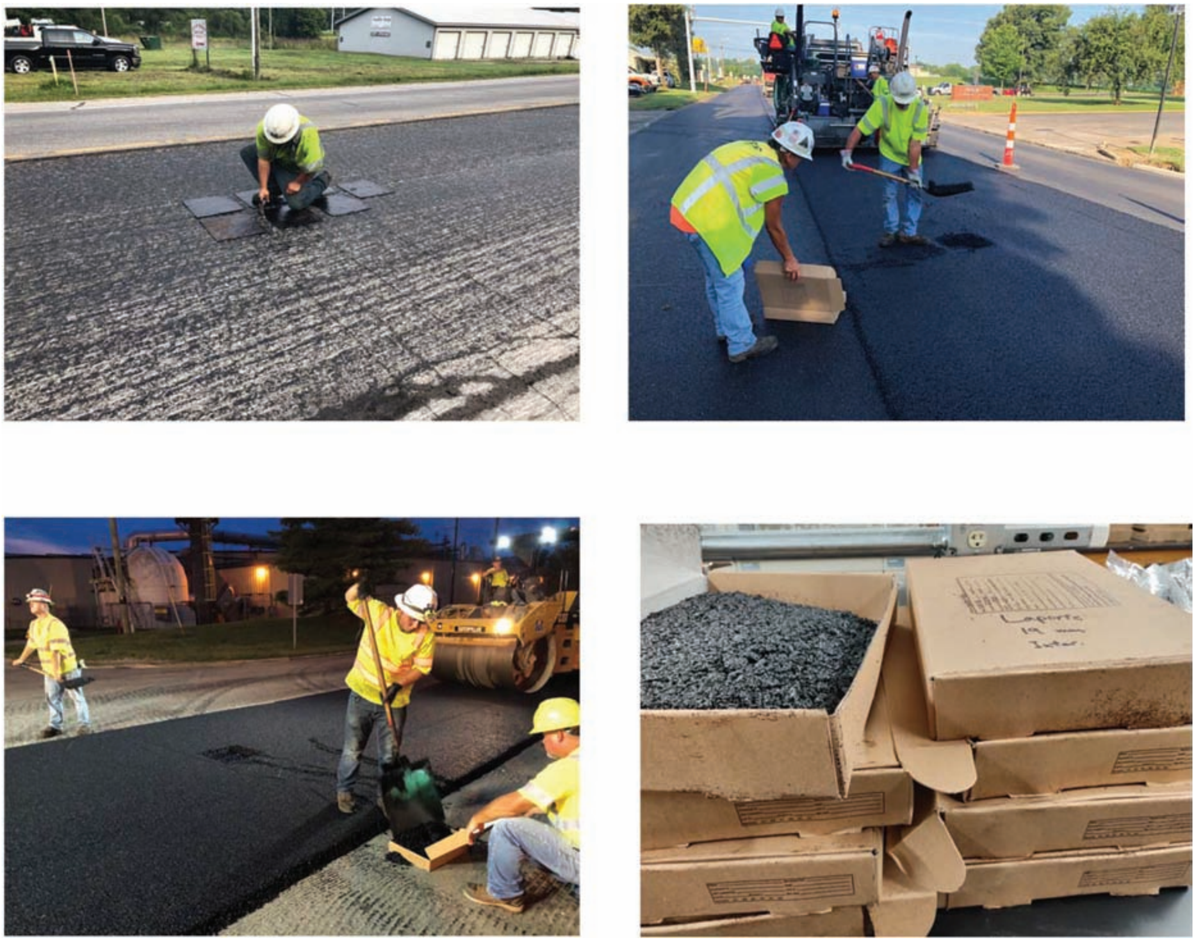


Figure 4.1 Sample collection at a Superpave 5 project site.

TABLE 4.1
Overview of Superpave 5 projects

Location	Quantity of Asphalt Mixture Placed (tons)	Quantity of Asphalt Mixture for Which QC/QA Data Available (tons)
Fort Wayne, RS 40253	49,192	24,940
Crawfordsville, RS 38668	6,150	4,321
LaPorte, RS 38629	16,500	2,711
Greenfield, R 30280	16,441	14,400
Vincennes, RS 39353	32,308	13,920
Vincennes, R 36648	7,185	7,100
Seymour, RS 39149	12,636	4,274
Seymour, RS 36176	3,180	1,979

from the QC/QA data were aggregate gradation, fineness modulus, aggregate effective specific gravity (G_{se}), effective binder content (P_{be}), effective binder volume (V_{be}), laboratory air voids content, laboratory VMA, and pavement density. The compaction information and procedures were also obtained from field observations.

A brief overview of the projects is given in Table 4.1. Information on quantity of asphalt (tons) placed was obtained from the Contract Information Book (CIB) available on the INDOT website. Asphalt mixture quantities for which QC/QA data were available for the projects was obtained from Percent Within Limits (PWL) workbooks provided by INDOT. The data in Table 4.1 indicates the Fort Wayne project, RS 40253 produced the highest quantity of asphalt mixture, whereas the Seymour project, RS 36176 had the lowest quantity.

To complete the primary objective of analyzing the construction data for compliance with Superpave 5 specifications, two main mixture properties were studied, laboratory air voids contents from the plate samples and pavement densities determined from field cores. Two sets of data were obtained for every test section, QC and QA.

TABLE 4.2
T-test result summary

District	Project Number	Air Voids Data Significantly Different?	Density Data Significantly Different?
Fort Wayne	RS 40253	Yes	No
LaPorte	RS 38629	No	No
Crawfordsville	RS 38668	No	No
Seymour	RS 39149	No	No
Seymour	RS 36176	Not available	Not available
Vincennes	RS 39353	Yes	No
Vincennes	R 36648	No	No
Greenfield	R 30280	No	No

As two groups of data were sampled from every test section, it was necessary to investigate whether the difference between them was statistically significant or not. Hence, for every project, both laboratory air voids contents and in-place density QC and QA data were t-tested assuming unequal variances, to determine whether the difference between them was statistically significant.

Table 4.2 shows the t-test results for eight of the projects. Seymour project RS 36176 was not t-tested due to lack of available data. The results show that on two projects, the laboratory air voids contents QC and QA data are statistically different. None of the projects showed a statistically significant difference between the QC and QA in-place density.

5. FORT WAYNE (RS 40253)

5.1 Overview and Observations

The Fort Wayne project involved HMA Overlay, Minor Structural improvement of the existing pavement including some partial/full depth patching as necessary on US 30 from 700 ft. west of SR 13 to 600 ft. east of SR 5 in Kosciusko and Whitley Counties. The paving project was approximately 4.76 miles in length. This road section can be classified as a Rural Principal Arterial highway. Thus, it consists of eastbound and westbound lanes, separated by a grass median. Typical cross sections involve a four-lane divided road with paved shoulders. Thru lanes show a typical width of 12 ft., and inner and outer edge shoulders display a typical width of 4 ft. and 10 ft., respectively. Typical cross sections also included right- and left-turn lanes, wherever required. The current traffic characteristics for this pavement section are estimated at 22,860 average annual daily traffic (AADT) with 29.43% commercial vehicles.

The existing pavement entailed an HMA layer over concrete pavement. The HMA layer and concrete pavement had an estimated thickness of about 9.5 in. and 7 in., respectively. The existing pavement was carefully observed for cracking, deterioration, and other types of failure prior to milling and placing additional pavement. The milling operations involved removing 1.5 in. from the existing pavement surface to create a uniform profile across the pavement section, including mainline and shoulder. Then, a 1.5-in. HMA surface layer was placed on top of a 2.5-in. intermediate HMA layer.

Three different mixture designs were used to complete the project. First, a 19.0-mm intermediate mixture was applied to pave the mainline and shoulder. The aggregate materials used for the intermediate layer are #8 limestone, #12 limestone, #24 manufactured sand, #23 natural Sand, coarse RAP, and baghouse fines. The natural sand aggregate consisted of three composites obtained from different sources. The binder types used to prepare the mainline and shoulder intermediate mixtures were PG 76-22 and PG 64-22, respectively.

Second and third mixture designs were used to prepare 9.5-mm surface mixtures for the shoulder and mainline pavement sections, respectively. The shoulder surface mixture was prepared using #11 limestone, #12 limestone, #24 manufactured sand, #23 natural sand, fine RAP, and baghouse fines. The natural sand material consisted of three composites obtained from different sources. A PG 64-22 was selected as the proper binder type for the shoulder surface. The mainline surface mixture consisted of #11 limestone, #12 limestone, #24 manufactured sand, #11 steel slag, fine RAP, and baghouse fines. A polymer modified PG 76-22 was selected as the appropriate binder type to pave the mainline surface. Steel slag was added to the mainline surface mixture to provide improved frictional properties, stripping resistance, stability, and resistance to rutting. The amount of material placed for each mixture type were 4,150 tons of shoulder surface mixture, 7,177 tons of shoulder intermediate mixture, 14,552 tons of mainline surface mixture, and 23,062 tons of mainline intermediate mixture. The asphalt mixtures were produced in a drum mix facility located at Ardmore, Indiana, approximately 33 miles from the paving location.

Paving operations took place from June 6, 2018, to July 19, 2018. The research team visited the project on July 11, 2018. On that day, a section of the westbound passing lane was paved near Pierceton, Indiana. The paving train included a material transfer vehicle (MTV), paving machine and three rollers (breakdown, intermediate, and finish). The breakdown roller had an operating weight of 18.5 tons and a compaction width of 84 in. The intermediate roller had an operating three weight of 18.5 tons and a compaction width of 84 in.

The finish roller had an operating weight of 14 tons and a compaction width of 78 in. The contractor made an effort to apply breakdown rolling between 280°F and 300°F, intermediate rolling between 180°F and 210°F, and finish rolling between 150°F and 180°F, Frequently, roller operators took surface measurements using a temperature gun to perform rolling at the prescribed mat surface temperatures. This effort was made to avoid a potential tender mixture zone, between 210°F and 240°F.

Although slag aggregate provides several long-term benefits, it imposes a challenge for compaction because it cools faster than traditional aggregates. This effect makes the mixture cool more rapidly on the top and bottom of the layer than it does near the middle, causing a differential of temperature and stiffness throughout the HMA layer. Each roller applied seven passes, for a total of 27 passes. The mixture was placed and compacted, without complications. No mixture tenderness was observed during compaction. Plate samples and cores were extracted according to INDOT specifications, and without difficulties.

5.2 Data Analysis

There were four different mixtures in Fort Wayne project. The mixtures' job mix formula (JMF) information including course type, mixture type, binder content, VMA, and Gmm are presented in Table 5.1.

Figure 5.1 shows the average binder content values for different mixtures. Generally, QC samples showed a slightly higher binder content. However, the binder content obtained from both QC and QA samples are very close to the design binder content of 5.4% for the 19.0-mm mixtures and 6.5% and 5.8% for 9.5-mm mixtures.

The average air voids contents and mat densities are presented in Figures 5.2 and 5.3. Generally, the air void contents are in the range of 5.0% to 5.8%. The QC samples' air voids contents tend to be closer to 5% than do the QA samples, likely due to the higher binder contents in QC samples. Figure 5.3 indicates that all the mixtures have mat densities less than 95%.

Figure 5.4 shows the average VMA values for Fort Wayne mixtures. Based on the JMF information, the 19.0-mm mixture had a design VMA of 15.2%, while the design VMA for the 9.5-mm mixtures (182061 and 182068) are 17.1% and 16.9%, respectively. The QC and QA data indicate lower than anticipated VMA values for all the mixtures.

Figure 5.5 shows the distribution of the air voids content data in uniformly spaced 0.5% increments for both QC and QA data. The data represent 58 as-constructed data points and 61 laboratory data points. The mean and standard deviation values of air voids contents for QC specimens were 5.2% and 0.63%, respectively, while the QA specimens have 5.5% and 0.76% air voids content, respectively. Although, the air void of both QC and QA mixtures are slightly higher than the Superpave 5 target air voids content of 5.0%, the QC specimens are closer to the target.

The distribution of mixture densities is shown in Figure 5.6. Most of QC and QA data are distributed between 93% to 95%. However, a few results show very low densities of 92% or less; 75% of the total data

TABLE 5.1
Mix information (Fort Wayne-40253)

Mix ID	Mixture	Course	P_b (%)	VMA (%)	G_{mm}
182057-76	19.0 mm	Intermediate	5.4	15.2	2.507
182057-64	19.0 mm	Intermediate	5.4	15.2	2.507
182061-64	9.5 mm	Surface	6.5	17.1	2.475
182068-76	9.5 mm	Surface	5.8	16.9	2.643

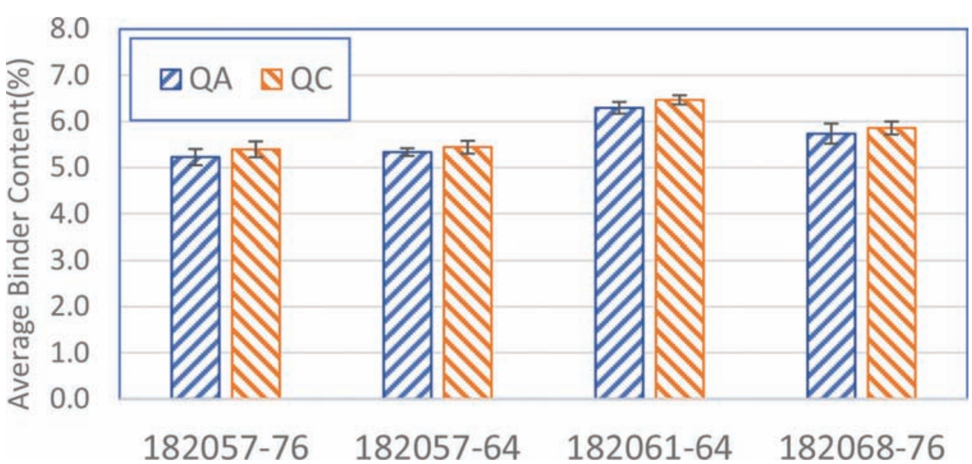


Figure 5.1 Average binder content (Fort Wayne-40253).

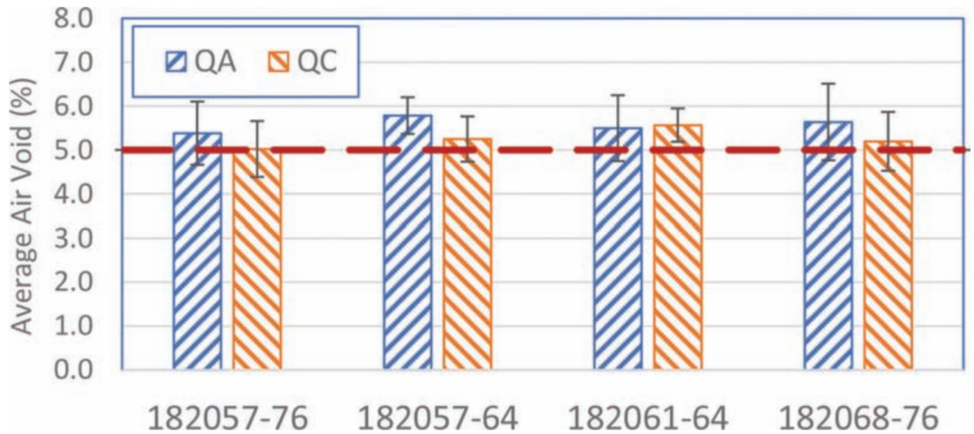


Figure 5.2 Average air voids content (Fort Wayne-40253).

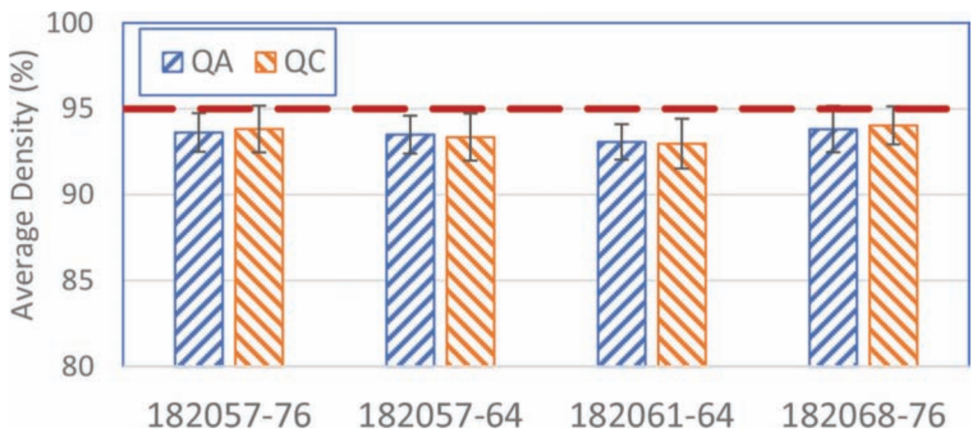


Figure 5.3 Average density (Fort Wayne-40253).

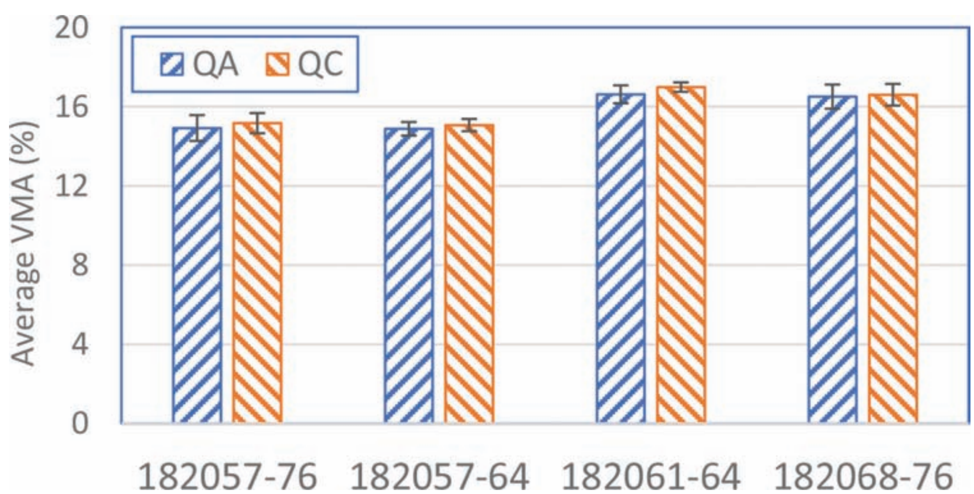


Figure 5.4 Average voids-in-the-mineral-aggregates (Fort Wayne-40253).

points lie below 95%, the target density for Superpave 5 mixtures. The average density for QC and QA samples are similar (93.8% and 93.6%, respectively), but both are lower than the 95% target. Moreover, the median of both the QC and QA data ranges are approximately 94%, indicating that the mixture was under-compacted by about 1%.

The overall average laboratory air voids content was 5.5% while the overall average in-place density was 93.6%. Figure 5.7 is a plot of all the laboratory air voids and in-place density data. The plot shows most of the air voids content data are spread between 4% and 6.5%, but most of the field densities are below the 95% line, indicating the mixture was somewhat under-compacted.

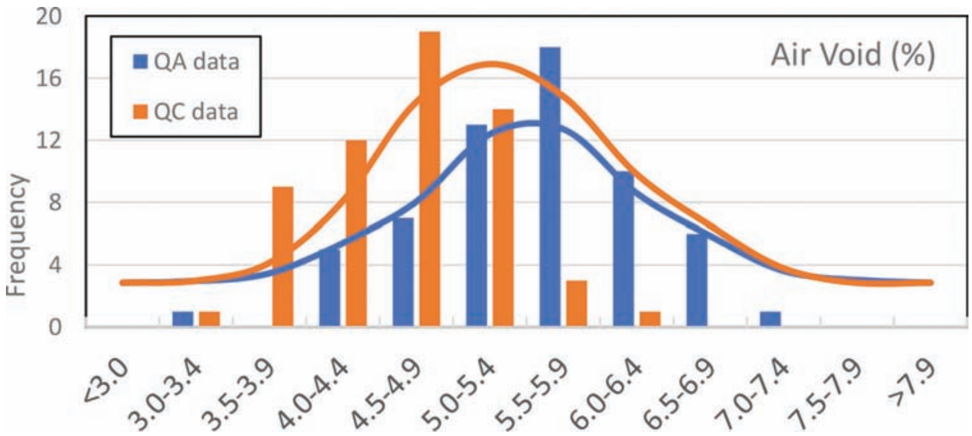


Figure 5.5 Air voids content distribution (Fort Wayne-40253).

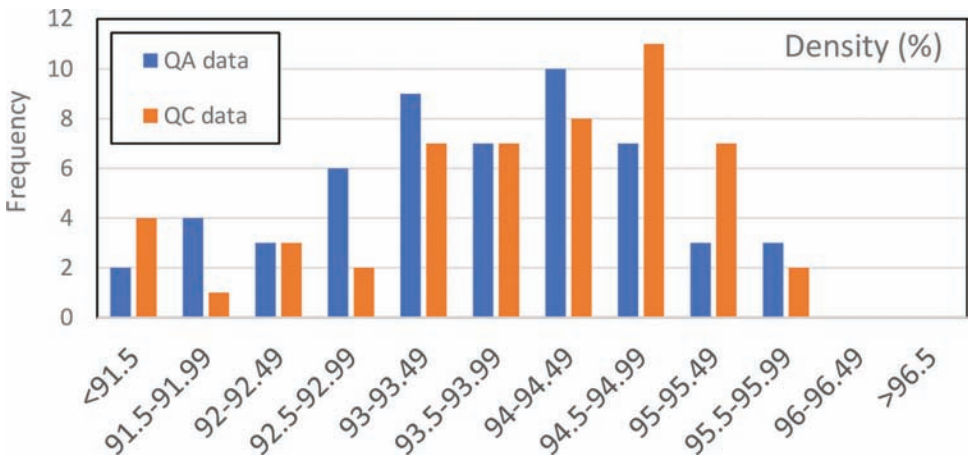


Figure 5.6 Density distribution (Fort Wayne-40253).

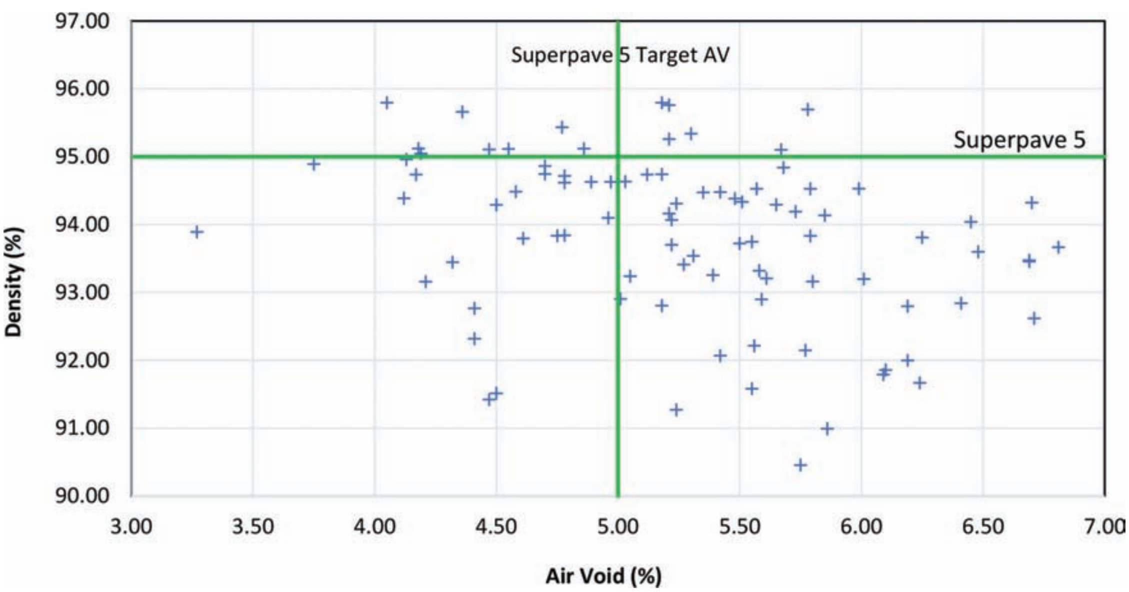


Figure 5.7 Volumetric data summary (Fort Wayne-40253).

6. LAPORTE (RS 38629)

6.1 Overview

Project RS 38629 in the LaPorte District was an asphalt mixture overlay and preventive maintenance work on SR 23. The length of the project was 400 ft. and involved 16,500 tons of mixture. The project consists of a 12.5-mm surface mixture applied to the road mainline. This project was not visited by Purdue research team.

6.2 Data Analysis

Based on JMF information, the binder content, VMA and G_{mm} values are 6.1%, 16.1%, and 2.499%. Only 10 QC/QA data points were reported for the LaPorte (RS 38629) project from 5 sublots. The air voids content distribution is shown in Figure 6.1. The average air voids contents for QC and QA samples are 4.8% and 4.9%, respectively, which are very close to the Superpave 5 target. However, the range of air voids content quite wide, from 3.2% to 6.0%.

Figure 6.2 shows the in-place mixture density distribution. More than 95% of the data lies below the 95% density mark required by Superpave 5. The average density for QC and QA data are 94.0% and 94.3%, respectively.

The binder content and VMA data are presented in Figures 6.3 and 6.4. Figure 6.3 shows the binder contents of QC samples is slightly higher (shifted to the right) than those of QA samples, with the average values of 6.2% and 6.0% for QC and QA, respectively. The binder contents of both QC and QA samples are close to the design binder content of 6.1% (JMF). Finally, Figure 6.4 indicates the QC samples had slightly higher average VMA (16.2%) than the QA samples (15.8%). The JMF lists the design VMA as 16.1%.

Overall, for the QC and QA data together, the average laboratory air voids were 4.9% while the overall average in-place density was 94.2%. Figure 6.5 is a plot of all the laboratory air voids content and in-place density data and shows that nearly all the field densities are 93% and 95%.

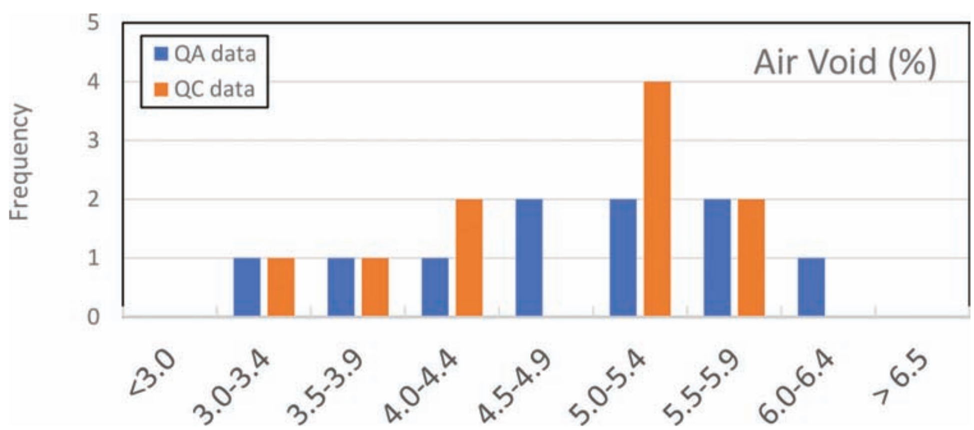


Figure 6.1 Air void distribution (Laporte-38629).

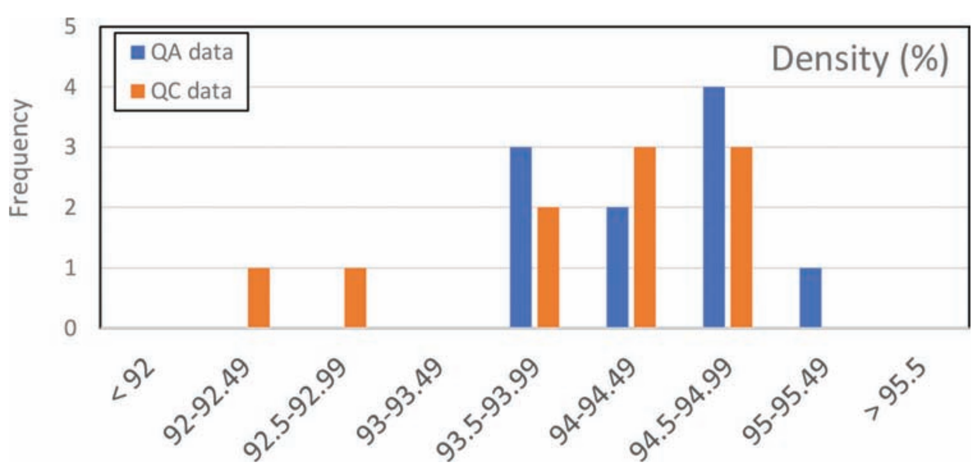


Figure 6.2 Density distribution (Laporte-38629).

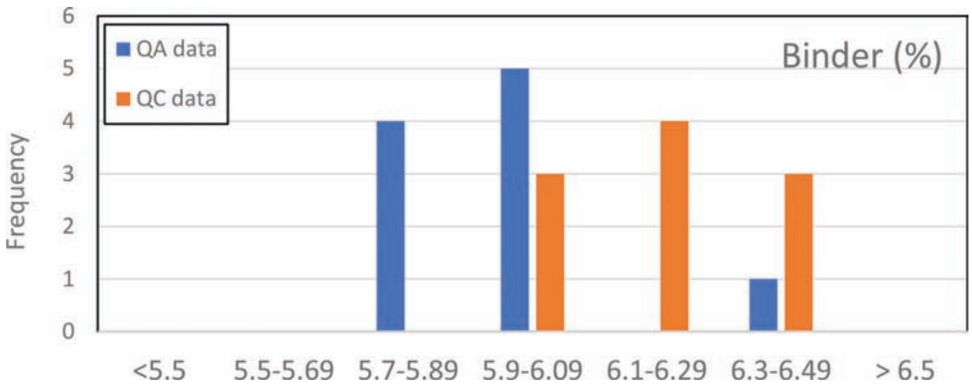


Figure 6.3 Binder content distribution (Laporte-38629).

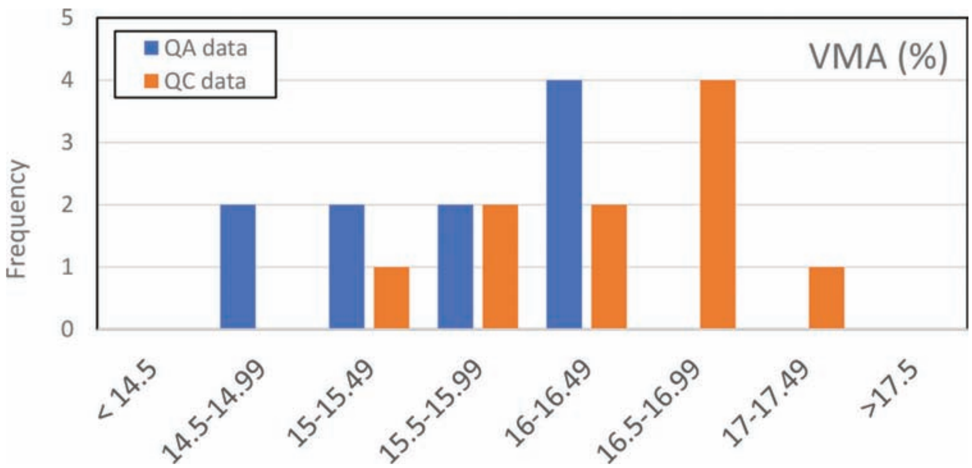


Figure 6.4 VMA distribution (Laporte-38629).

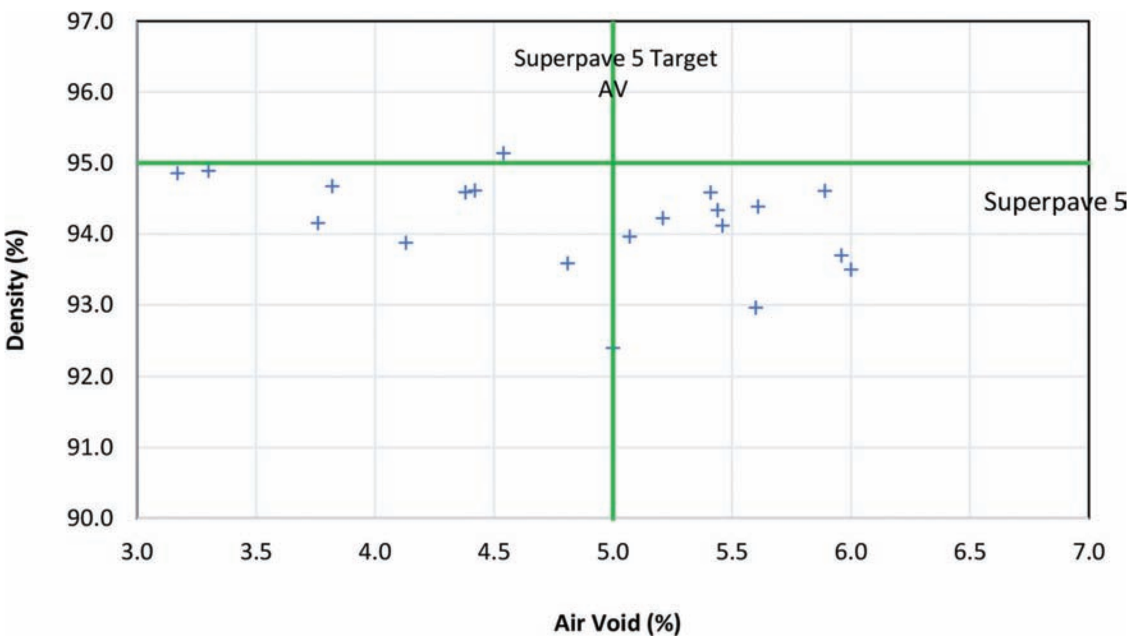


Figure 6.5 Volumetric data summary (Laporte-38629).

7. CRAWFORDSVILLE (RS 38668)

7.1 Overview and Observations Information

The RS 38668 Crawfordsville District project was performed along a pavement section of US 231 in Crawfordsville, Indiana. The scope of work for the project included milling approximately 1.5 in. of the existing asphalt and overlaying the pavement with 1.5 in. of new mixture. The paving project was approximately 1.9 miles in length and extended from roughly 0.18 miles south of SR 32 (at Grant Avenue) to 0.29 miles north of US 136 (at Sugar Creek). The roadway can be described as an Urban Principal Arterial road section with two lanes in both directions with isolated raised medians and turn lanes. Typical section widths for the southbound and northbound lanes vary between 14.5 and 42.5 ft. The current traffic characteristics for this pavement section are estimated at 21,780 average annual daily traffic (AADT) with 5% trucks.

Test borings drilled into the existing travel lanes encountered two different pavement cross-sections, one consisting of asphalt pavement overlying aggregate base, the second asphalt pavement overlying Portland cement concrete (PCC) on an aggregate base. Existing average total pavement thickness was about 19 in. with a range measured between 14 to 24 in. thick. Below both existing pavement cross-sections the roadway test borings primarily encountered low to medium plasticity soils consisting primarily of silty loam (A-6) and silty clay loam (A-6). Any portions of pavement exhibiting excessive cracks, distress, or failure were removed and reconstructed prior to milling and resurfacing.

The total amount of new Superpave 5 asphalt mixture placed on the project was estimated to be roughly 4,320 tons, the remainder of the project being completed with conventionally designed Superpave mixture. For performance comparison purposes, one lane in each direction was paved with the conventional mixture while the other was paved with the Superpave 5 mixture. The Southbound passing lane and Northbound driving lane were paved using the Superpave 5 mixture. Conversely, the Southbound driving lane and the Northbound passing lane were paved using the conventional mixture. The asphalt mixture type used to pave the turning lane sections was determined based on what was most easily available at the time of construction, either conventional or Superpave 5.

The project used an INDOT 9.5-mm, Category 3 surface mixture with a polymer modified PG 70-22. The aggregate materials were a #11 crushed dolomite, #12 crushed dolomite, #24 dolomite sand, 3/8-in. fracture RAP, and baghouse fines. Both asphalt mixtures were produced in a drum mixture facility located at Lafayette, Indiana, approximately 34 miles from the paving location.

Paving operations took place from June 27 to September 17, 2018 and suffered some delays due to rain. Additionally, the paving work was performed at night. The Purdue team visited the project on August 19, 2018 and observed that paving material was transported from the asphalt plant and placed at the construction site without interruptions. The paving train consisted of a material transfer vehicle (MTV), paving machine and three rollers (breakdown, intermediate, and finish). The breakdown roller had an operating weight of 13 tons and a compaction width of 79 in., the intermediate an operating weight of 14 tons and a compaction width of 78 in., and the finish roller an operating weight of 13 tons and a compaction width of 78 in. The number of passes applied by the breakdown, intermediate and finish rollers were eleven, nine, and seven, respectively. Pavement mat surface temperature measurements were taken by the Purdue team between the breakdown and intermediate roller. In general, the pavement mat temperatures were between 190°F and 240°F. The contractor used a non-nuclear density gauge to control the compaction effort. Gauge density measurements were made at three different locations across the pavement mat and the locations marked, in order to take additional density readings after every roller pass. INDOT-required quality assurance was completed without difficulties.

7.2 Data Analysis

A limited number of data were reported for the project. The Crawfordsville project includes one 9.5-mm surface mixture applied on the mainline. Based on JMF information, the binder content, VMA, and G_{mm} values are 6.1%, 16.6%, and 2.544%, respectively.

The average laboratory air voids contents of the QC and QA data are 5% and 4.3%, respectively. The distribution of air voids content data is shown in Figure 7.1. While the QC samples had an average air voids content of 5%, only one-third of the QC data are in the 4.5%–5.5% range. Average QC and QA mat densities are 93.7% and 94.1%, respectively. Figure 7.2 shows that most mat densities are 94.5% or less.

The binder content distribution is presented in Figure 7.3. The data are distributed in a range from 5.9% to 6.5%, with an average of 6.2% for both the QC and QA data, indicating good agreement with the design binder content of 6.1%. The VMA distribution plotted in Figure 7.4 do not indicate much difference between QC (average of 15.9%) and QA (average of 15.7%) VMA values of these data. Both average values are below design VMA of 16.6%.

The overall average laboratory air voids content for this mixture was 4.7%, while the overall average in-place mat density was 93.7%. Figure 7.5 is a plot of all the laboratory air voids content and in-place density data. The plot indicates most of the mat densities lie below the 95% line, while the air voids contents are scattered in a range of 3% to 6%.

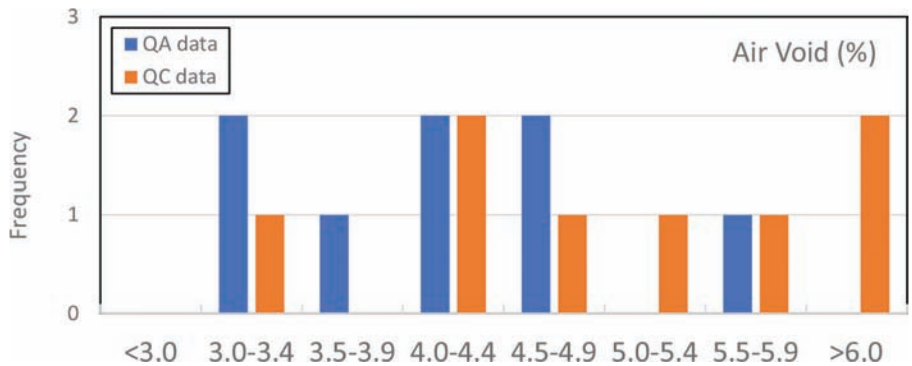


Figure 7.1 Air voids content distribution (Crawfordsville-38668).

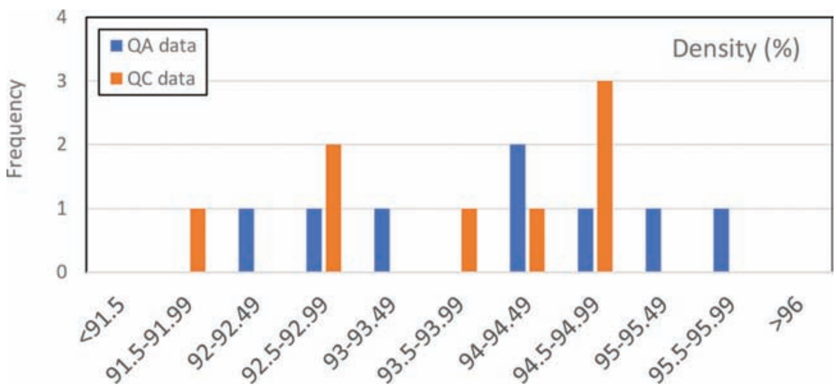


Figure 7.2 Density distribution (Crawfordsville-38668).

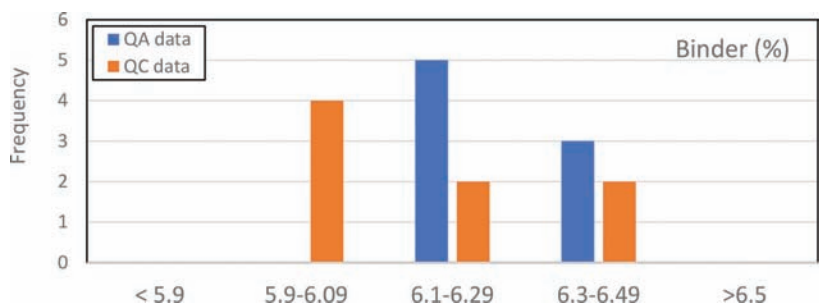


Figure 7.3 Binder content distribution (Crawfordsville-38668).

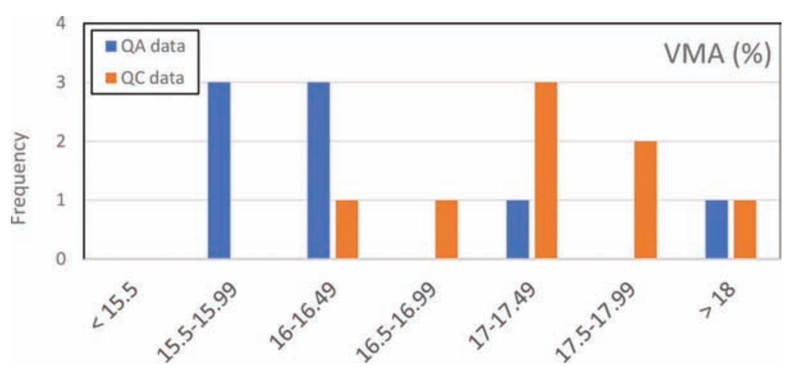


Figure 7.4 VMA distribution (Crawfordsville-38668).

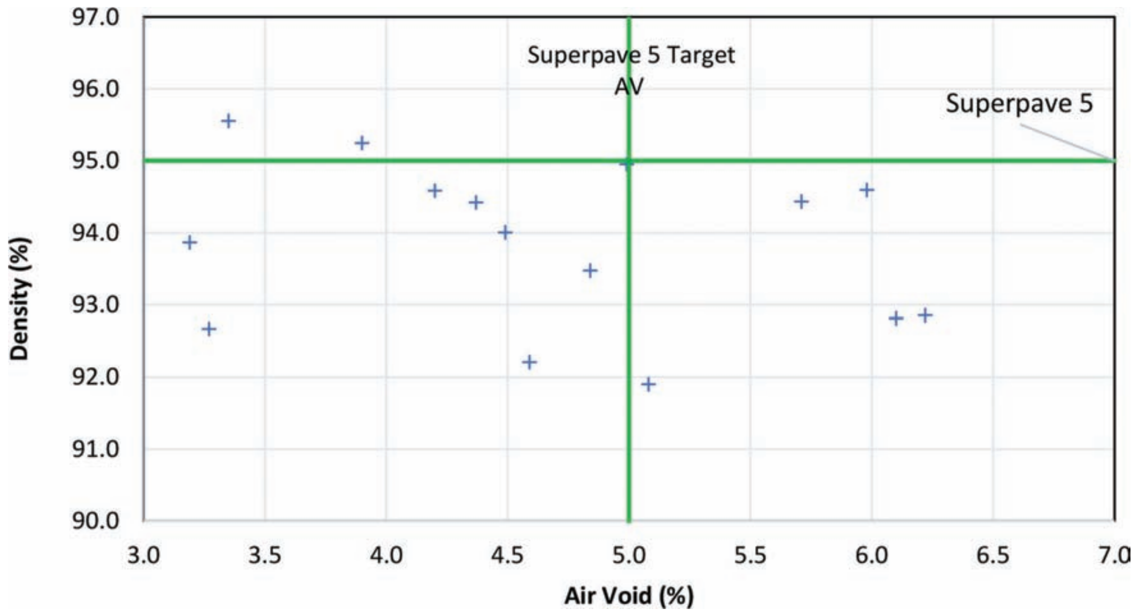


Figure 7.5 Volumetric data summary (Crawfordsville-38668).

8. SEYMOUR (RS 39149)

8.1 Overview and Observation Information

The Seymour District project RS 39149 involved pavement preservation of approximately 5.38 miles of US 231 located in Owen County, Indiana. The project took place along the US 231 route beginning at State Road 46 and extending to State Road 67. The road section can be classified as a Rural Principal Arterial exhibiting a rolling terrain and provides a two-lane roadway in each direction. Typical lane widths are 12 ft., with shoulder widths varying between 2 and 10 ft. Project scope consisted of a mill and resurface. The existing pavement displayed longitudinal and transverse distresses, from medium to low severity. At certain locations, full or partial depth reconstruction was performed prior to milling and resurfacing. The current traffic characteristics for this pavement section are estimated at 8,680 AADT with 10% trucks.

The existing pavement thicknesses were determined using pavement core samples and soil borings. Based on six pavement core samples, the existing total thicknesses varied from approximately 10 to 22 in. In four of the six cores, the asphalt was underlain by PCC. The asphalt thickness observed in the cores ranged from 10 to 13 in., while the PCC varied in thickness from 6 to 10 in. The soil borings data indicated the existing asphalt pavement varied in thickness from approximately 10 to 14 in. Seventeen of the 22 soil borings indicated the asphalt was underlain by PCC varying in thickness from 6 to 12 in. At two of the boring locations the asphalt pavement was underlain by approximately 6 to 8 in. of crushed stone. The remaining pavement sections exhibited base layers, sub-base layers, or both of unknown characteristics. The predominant and critical soil types encountered were clay loam (A-6) and silty clay loam (A-7-6).

Project plans called for a 9.5-mm, Category 3 surface mixture with a polymer modified PG 70-22 binder. The aggregates for the project were a #11 crushed stone, #12 crushed dolomite, #24 stone sand, 3/8-in. fractured RAP, and baghouse fines. A single surface mixture was applied to mainline and shoulder sections. The total amount of new Superpave 5 asphalt mixture was estimated at about 7,274 tons. The asphalt mixture material was produced in a drum mix facility located at Bloomfield, Indiana, approximately 28 miles from the paving location.

The paving operations on US 231 took place from August 24 to September 4, 2018. The Purdue team visited the project on August 24, 2018, the day the northbound lane was paved from SR 67 to Coon Path Road, a length of approximately 1.2 miles. The paving train operated in the opposite direction of traffic and consisted of a material transfer vehicle (MTV), paving machine and three rollers (two breakdown and one finish). Immediately behind the paver, two breakdown rollers ran in echelon to cover the full lane-width. The finish roller followed the breakdown rollers, carefully working the longitudinal joint and mat width. All three rollers had an operating weight of 13 tons and a compaction width of 79 in. The number of passes applied by the breakdown and finish rollers were thirteen and nine, respectively. Overall, the asphalt mixture was placed without complications.

8.2 Data Analysis

The air voids content data reported for Project RS 39149 are presented in Figure 8.1. The average air voids contents for the QC and QA data are 4.9% and 4.6%, respectively. Although the average values are close to the 5% target, the data are distributed in a wide range from 3% to 7% with standard deviations of 1.1% (QC) and 1.2% (QA).

The QC and QA mat density distribution are shown in Figure 8.2. Similar to the air voids content, the mat densities lie in a wide range, from 90% to 97%. The average densities of 93.9% (QC) and 93.5% (QA) suggests a higher compaction effort may have been needed.

The JMF for the project indicates a design binder content of 6.2% and design VMA of 16.5%. The average binder content for QC and QA data are 6.5% and 6.1%, respectively. As shown in Figure 8.3, the QA samples tended to have lower binder contents compared to the QC samples. Figure 8.4 shows the VMA values distributed in a range from 14% to 18%, with the average QC and QA VMA values of 16.8% and 16.5%, respectively.

Figure 8.5 provides an overview of laboratory air voids content and mat density data for the project. The

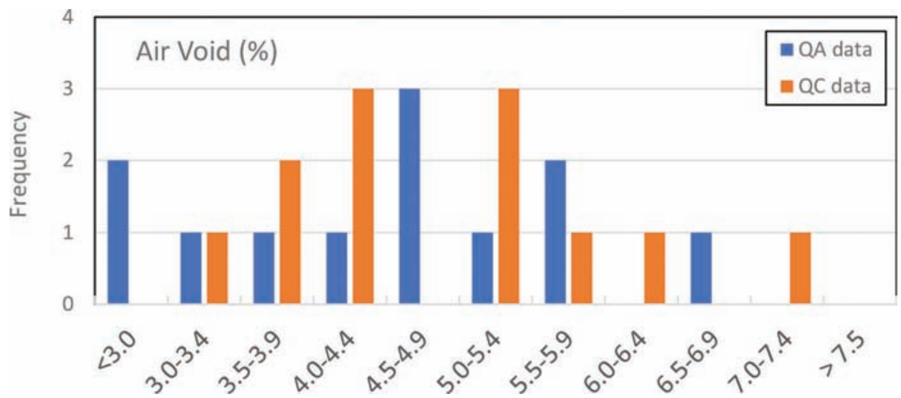


Figure 8.1 Air voids content distribution (Seymour-39149).

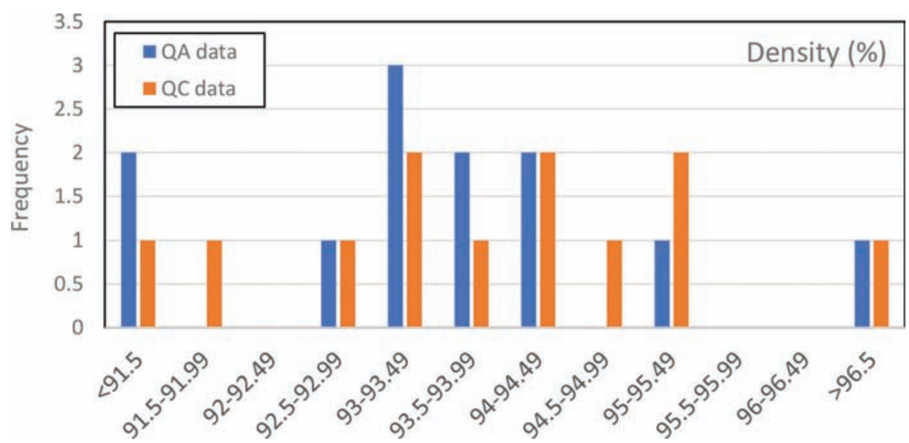


Figure 8.2 Density distribution (Seymour-39149).

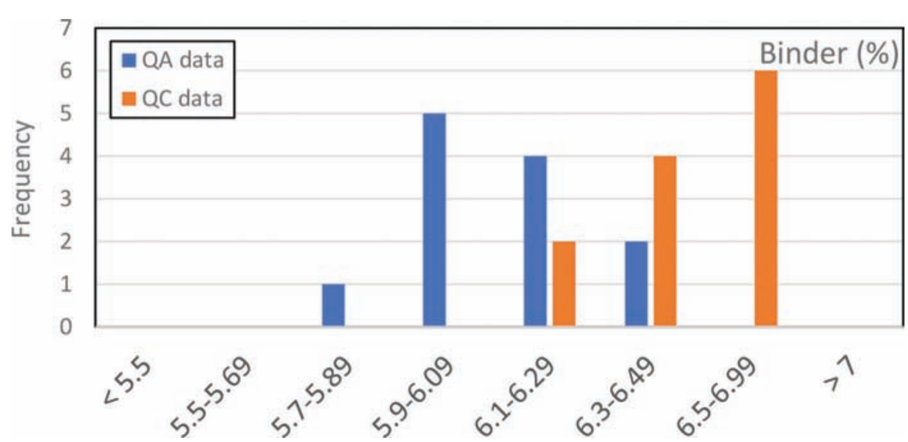


Figure 8.3 Binder content distribution (Seymour-39149).

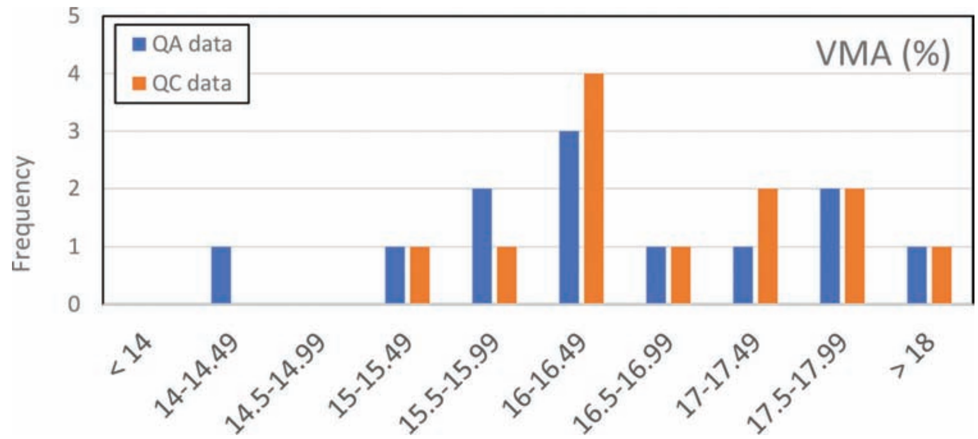


Figure 8.4 VMA distribution (Seymour-39149).

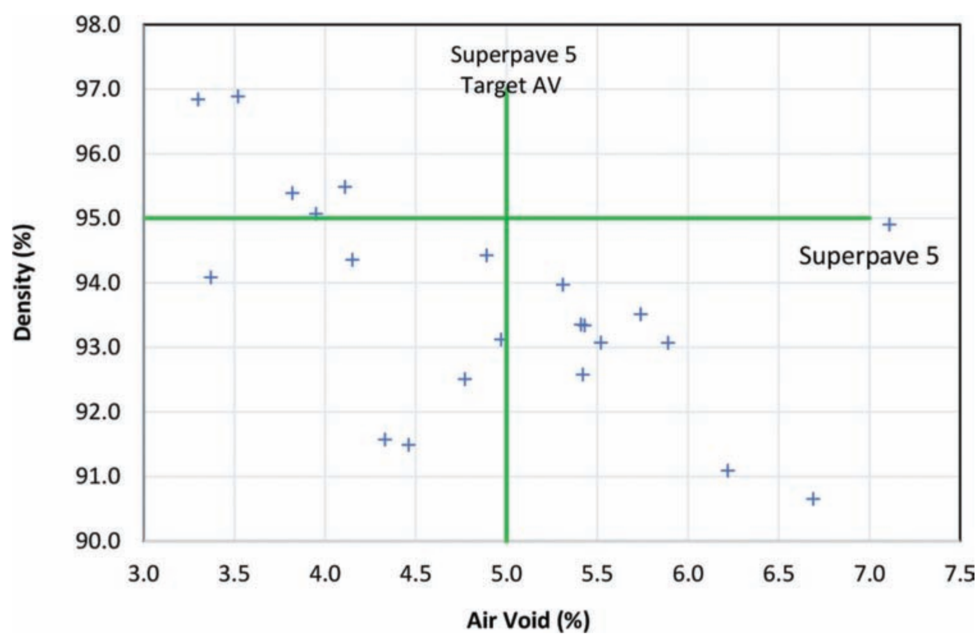


Figure 8.5 Volumetric data summary (Seymour-39149).

overall average in-place density was 93.75 with most of the density data points near or below the 95% target density, and a wide range of values, from 90%–97%, indicating high variability. The air voids contents are scattered about the 5% target value with an overall average value of 4.7%.

9. SEYMOUR (RS 36176)

9.1 Overview

Project RS 36176 in the Seymour District was an asphalt overlay and preventive maintenance work on US 50. The length of the project was 593 ft. and involved 3,180 tons of mixture. However, surface mixture data was not provided for this project. Only data for the intermediate and base layers were available; both mixtures were placed on the mainline. This project was not visited by the Purdue University research team.

9.2 Data Analysis

Very limited data from intermediate and base layers were reported for this project. Table 9.1 presents the JMF information for these two mixtures. There were two data sets (2 QA and 2 QC data points) from the 185171 base mixture. The average binder content for QC and QA samples are 4.9% and 4.7%, respectively. Both are lower than the design binder content of 5.1%. In spite of the low binder contents, the average air void values are 4.6% and 4.9%, only slightly lower than the 5.0% target. Additionally, the QC and QA samples taken from the base mixture have average densities of 93.5% and 87.4%, the latter suggesting some under compaction. Finally, the average VMA values for this mixture were 13.1% and 12.8% for QC and QA samples, respectively, both lower than the design VMA of 14%.

Only one data set was reported for the intermediate mixture (185172). The QC and QA samples had binder contents of 4.4% and 4.1%, both lower than the design binder content of 5.3%. The low binder contents almost certainly contributed to the higher air voids contents (6.4% and 7.3%) and low QA mat density of 92.3%. However, the QC mat density appears fine (94.8%). The QC and QA VMA values of 14.8% and 14.9% are higher than 14.3% design VMA.

TABLE 9.1
Mixture information (Seymour-36176)

Mix ID	Mixture Type	Course	P_b (%)	VMA (%)	G_{mm}
185171-64	25.0-mm	Base	5.1	14.0	2.519
185172-64	19.0-mm	Intermediate	5.3	14.3	2.513

Figures 9.1 through 9.2 show the data distributions for laboratory air voids content and mat density. The QC samples had an average air voids content of 5.4%, while the QA samples averaged 5.5%. The average mat density was 93.2% and 89.6% for the QC and QA samples, respectively. Both are lower than the targets of 5% for air voids content and 95% for mat density. The low binder contents likely contributed to the low air voids contents and mat densities.

Figure 9.3 shows the laboratory air voids contents and mat densities for the project. The overall average air voids content achieved was 5.4% and the

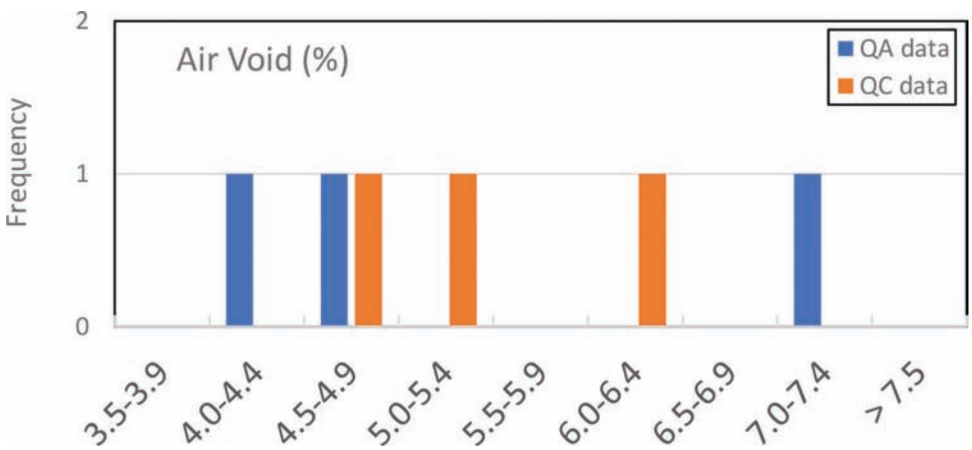


Figure 9.1 Air voids content distribution (Seymour-36176).

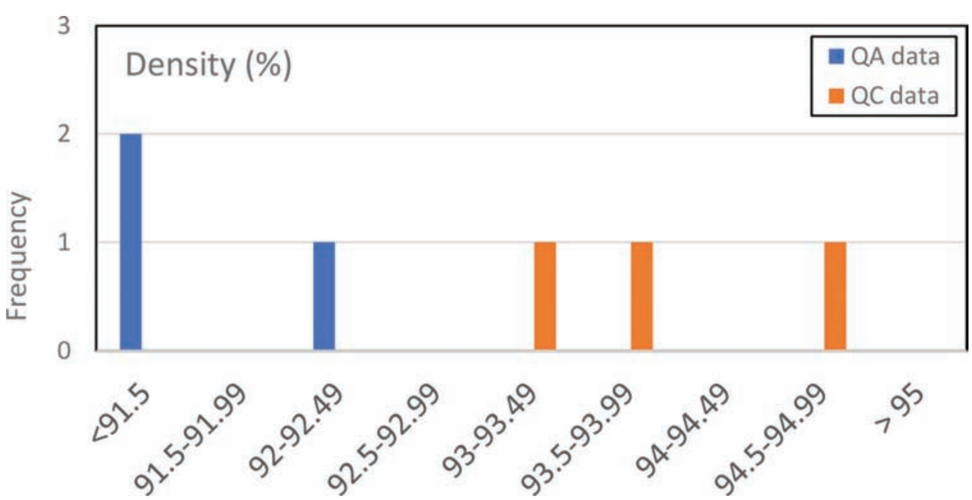


Figure 9.2 Density distribution (Seymour-36176).

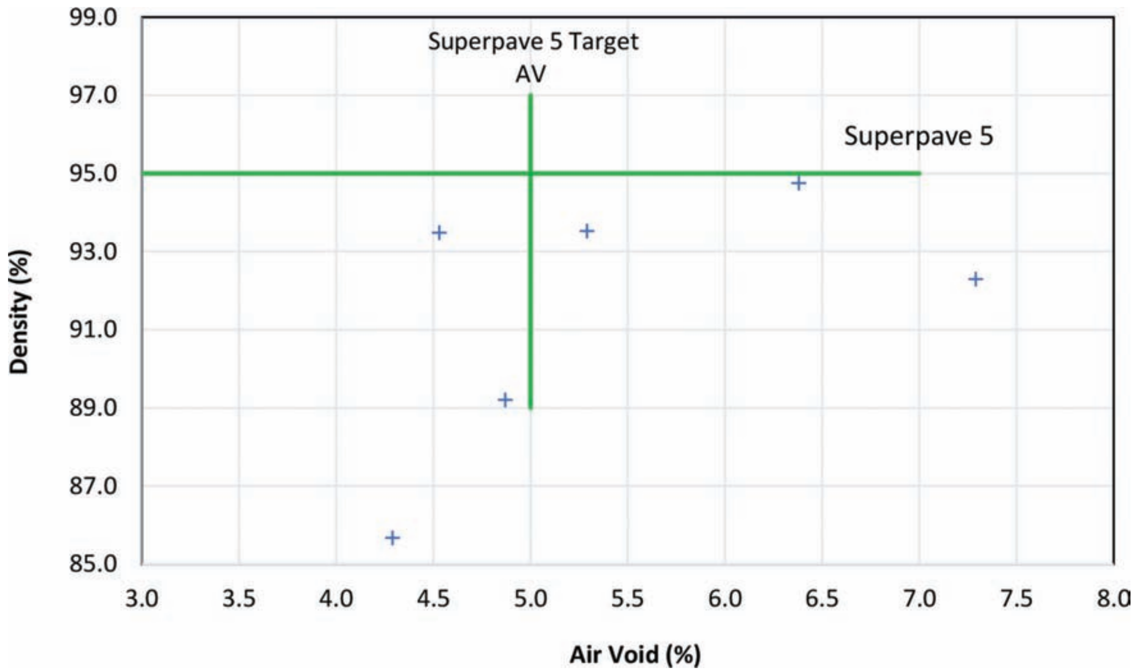


Figure 9.3 Volumetric data summary (Seymour-36176).

average mat density 91.5%. Although these values seem less than desirable, with the limited amount of data from the project, it is difficult to draw and certain conclusions.

10. VINCENNES (RS 39353)

10.1 Overview

Project RS 39353 in the Vincennes District was an asphalt mixture overlay and minor structural work on US 150. The length of the project was 1,372 ft. and involved 32,308 tons of mixture, including one surface and two intermediate mixtures, all three placed on the mainline. This project was not one of the projects visited by Purdue research team.

10.2 Data Analysis

The DMF information for the three mixtures are shown in Table 10.1. Figure 10.1 compares the average binder content for the different mixtures. Generally, a higher variation was observed for the QA samples. The average binder content measured for the 185093

TABLE 10.1
Mixtures information (Vincennes-39353)

Mix ID	Mixture Type	Course	P_b (%)	VMA (%)	G_{mm}
185093	9.5-mm	Surface	6.5	16.8	2.474
185099	19.0-mm	Intermediate	5.3	14.8	2.491
185383	19.0-mm	Intermediate	5.3	14.9	2.479

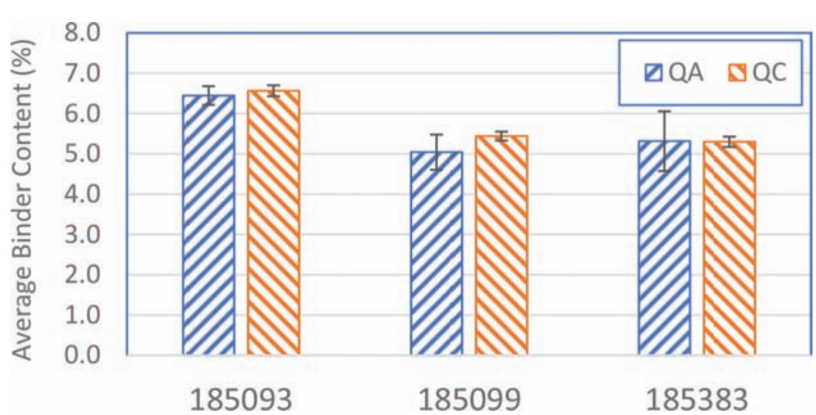


Figure 10.1 Average binder content (Vincennes-39353).

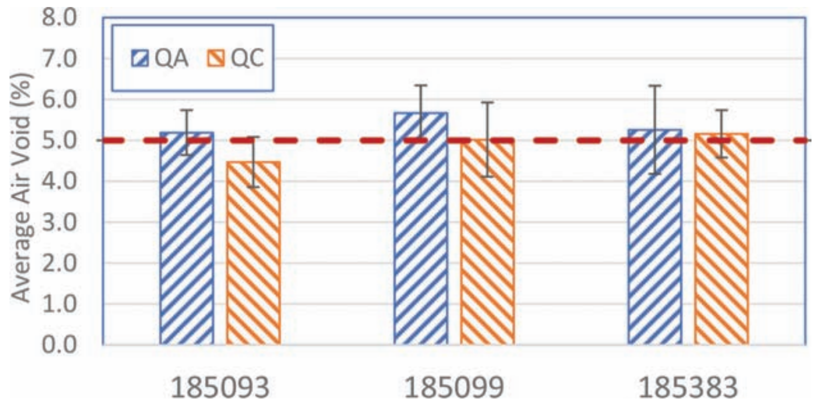


Figure 10.2 Average air voids content (Vincennes-39353).

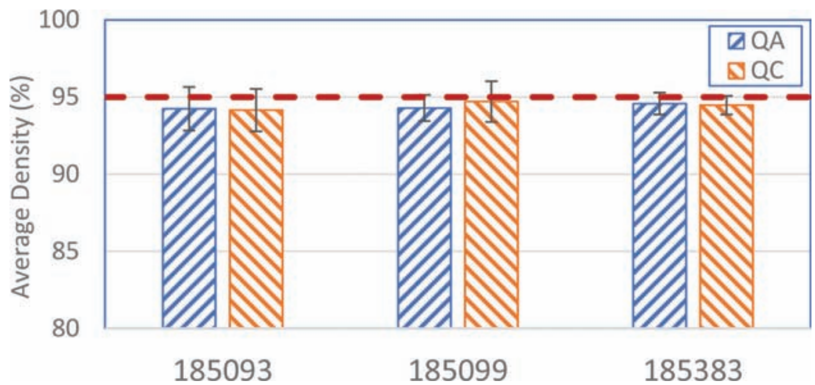


Figure 10.3 Average density (Vincennes-39353).

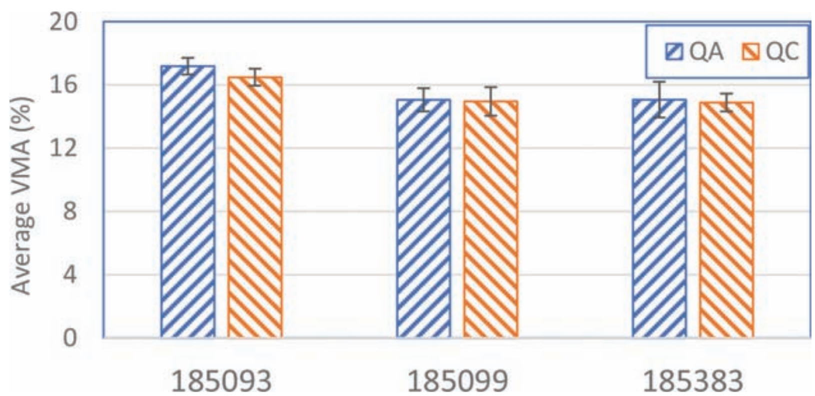


Figure 10.4 Average VMA (Vincennes-39353).

and 185383 mixtures are very close to their respective design binder contents of 6.5% and 5.3%, while the average binder content of the QA samples is 0.3% lower for the 185099 mixture.

Figures 10.2 and 10.3 show the average air voids contents and mat densities for QC and QA samples taken from the different mixtures. With a reasonable standard deviation, the average air voids content of the mixtures are close to the 5% target, while the average mat densities are slightly lower than the 95% target.

The average VMA values for QC and QA samples are shown in Figure 10.4. These values are slightly higher than the design VMA presented in Table 10.1. Again, these higher VMA values are most likely the result of the slightly high binder contents.

The air voids content distribution is presented in Figure 10.5. It follows a normal distribution and ranges from 3% to 7.5%. The average air voids content for QC and QA samples are 4.7% and 5.2%, respectively, with a standard deviation of 0.7. Both the QC and QA averages are close to the 5% target.

Figure 10.6 indicates the mat density data is similarly distributed for QC and QA samples, with an average of 94.3% and standard deviation of 1.22 for both QC and

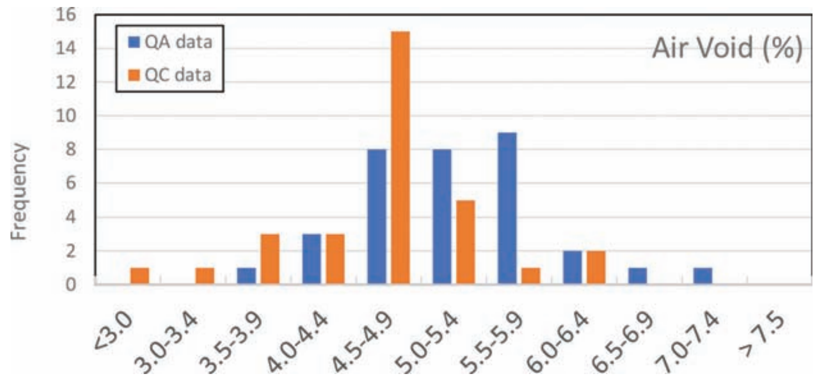


Figure 10.5 Air voids content distribution (Vincennes-39353).

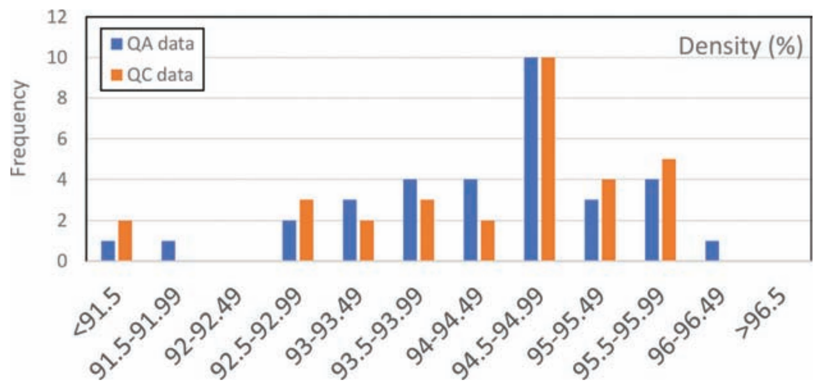


Figure 10.6 Density distribution (Vincennes-39353).

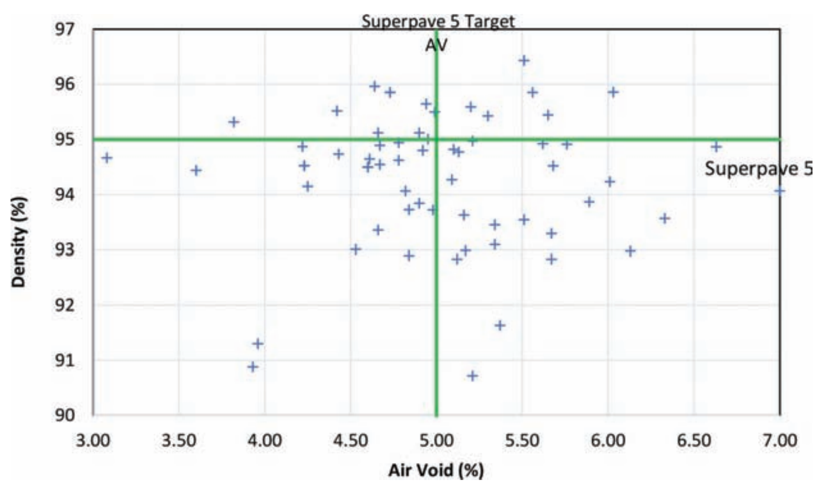


Figure 10.7 Volumetric data summary (Vincennes-39353).

QA data. Generally, while the mat may be slightly under-compacted, the contractor came close to the 95% target.

The overall average laboratory air voids content for the project was 5.0%, while the overall average mat density was 94.3%. Figure 10.7 represents an overview of laboratory air voids content and mat densities achieved. It can be observed that most of the data points are aggregated close to the Superpave 5 target lines, indicating the project had some success in producing and placing a Superpave 5 mixture.

11. VINCENNES (R 36648)

11.1 Overview and Observation Information

The Vincennes District project was carried out on SR 62 from Parke Street to Southwind Port Road in Mount Vernon, Indiana. This section of SR 62 can be classified as an Urban Principal Arterial east-west route. The paving project was approximately two miles in length. The road is predominantly three lanes in width including the center turn lane. However, a small portion of the pavement section is only two lanes wide, from approximately Tile Factory Road to Southwind Port Road (0.20-mile). Beyond Southwind Port Road, SR 62 transitions to a four-lane divided highway. Typical section widths for the westbound and eastbound travel lanes vary between 11 and 13 ft., while, the turning lane width typically ranges between 11 and 14 ft. The current traffic characteristics for this pavement section are estimated at 15,749 AADT with 14% trucks.

The existing pavement was cored at twenty locations to determine the existing pavement structure. In its majority, the existing pavement is 3 in. to 6 in. of asphalt overlying 6 in. to 9 in. of PCC. Additionally, the shallow subgrade soils encountered along the alignment generally consists of soft to medium stiff with occasional stiff, silty clay loam (A-6) and silty clay (A-7-6) to depths of 10 ft. below the existing ground surface.

A similar pavement cross-section was used to rehabilitate the east and westbound driving lanes. First, 4 in. of asphalt were milled from the existing pavement. Then, 2 in. of a 12.5-mm intermediate mixture was placed, followed by 2 in. of a 12.5-mm surface mixture. For the center turn lane, 2 in. of the existing material was milled off and replaced by 2 in. of a 12.5-mm surface mixture. A heavily damaged right turn lane section was reconstructed. This section was comprised of a treated subgrade (Type IC), 8-in. of 25-mm base mixture placed in two, 4-in. lifts, 2 in. of 12.5-mm intermediate mixture, and 2 in. of 12.5-mm surface mixture.

Three mixtures designs were used on the project, all Category 4 mixtures. A 12.5-mm surface mixture, a 12.5-mm intermediate mixture, and a 25-mm base mixture. The surface mixture consisted of #9 limestone, #11 limestone, #11 dolomite, #12 dolomite, #24 dolomite sand, #24 manufactured sand, 1/2-in. RAP, and RAS, with a PG 76-22 polymer modified binder. The materials in the intermediate mixture were a #9 stone, #11 stone, #12 stone, #24 manufactured sand, 1/2-in. RAP, and RAS, with a PG 76-22 polymer modified binder. The base mixture consisted of a #15 stone, #18 stone, #11 stone, #23 sand, and 1/2-in. RAP, with a PG 64-22 binder. The total amounts of surface, intermediate and base mixture placed were estimated at about 4,136, 2,946, and 537 tons, respectively. The asphalt mixtures were produced in a drum mix facility located at Evansville, Indiana, approximately 25 miles from the paving location. At the plant, the original mixture design formulas were adjusted for aggregate breakdown using predetermined adjustments, as reported by the contractor.

Paving operations on SR 62 were carried out between June 6 and October 22, 2018. The Purdue team visited the project on July 13, 2018. On this day, the west end of the project was paved from Parke Street to near Mann Street, approximately 0.1 miles. The surface mixture was placed for all three lanes. The paving train consisted of a paving machine and two rollers, one as the breakdown roller and the second as the finish roller. The breakdown roller had an operating weight of 15 tons and a compaction width of 84 in.; the finish roller had an operating weight of 11 tons and a compaction width of 66 in. Each roller applied 7 passes. Mat surface temperature measurements were taken behind the paving machine, breakdown roller, and finish roller. Recorded temperatures ranged 190°F to 300°F. Overall, the paving was completed without problems.

11.2 Data Analysis

The RS 36648 project included three mixtures: two 12.5-mm surface mixtures and one 12.5-mm intermediate mixture. The JMF information is provided in Table 11.1.

Figure 11.1 compares the average binder content of QC and QA samples from different mixtures. Compared to the design binder content, the intermediate mixture (184609) has a much lower binder content for both QC and QA samples. However, the binder content of two surface mixtures are reasonably close to their design binder contents.

The average air voids contents and mat densities are presented in Figures 11.2 and 11.3. Generally, air voids contents are lower than the 5% target. This difference is more evident for the QC samples with the average air voids of 3.7% to 3.9%. There is a considerable variation in the measured air void contents from 186410 mixture.

Although, the average density of the 186419 surface mixture is close to the 95% target density for both QC and QA samples, the other two project mixtures seem to be somewhat under compacted. The VMA results in Figure 11.4 also indicate the mixtures did not satisfy the VMA requirement, with the highest difference observed for the 184609 mixture.

Figure 11.5 shows the distribution of laboratory air voids content from the project. Except for one point, the air voids content data for both QC and QA samples are distributed to the left of the diagram, less than 5.0%. The average air voids contents for QC and QA samples are 3.9% and 4.6%, respectively, the QC air voids content being about 15% lower than in the QA samples.

In Figure 11.6, the mat density values are also skewed left, indicating lower values than the targeted 95%. The mat density values are distributed from 91.5% to 96.5%, with the average QC and QA density values being 93.9% and 93.5%.

TABLE 11.1
Mixture information (Vincennes-36648)

Mix ID	Mixture Type	Course	P_b (%)	VMA (%)	G_{mm}
186409	12.5-mm	Intermediate	6.2	16.2	2.461
186419	12.5-mm	Surface	6.5	15.7	2.470
186410	12.5-mm	Surface	6.2	16.2	2.461

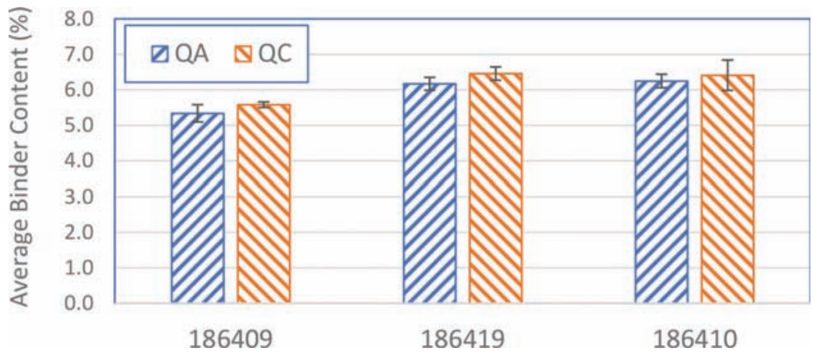


Figure 11.1 Average binder content (Vincennes-36648).

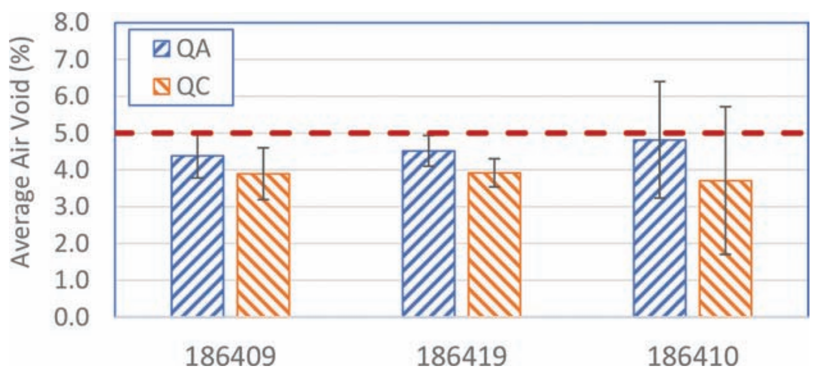


Figure 11.2 Average air voids content (Vincennes-36648).

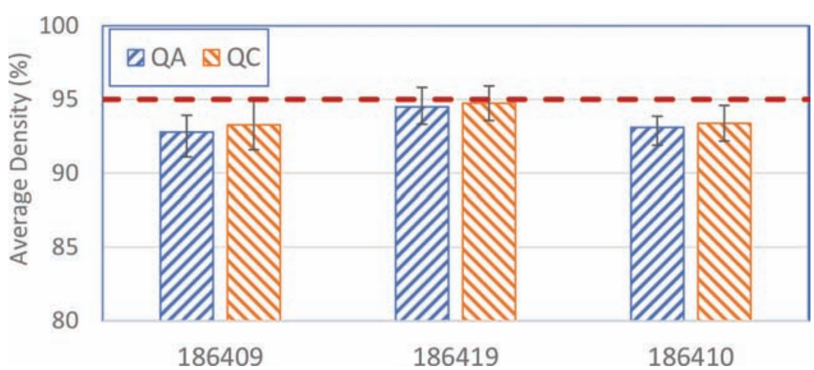


Figure 11.3 Average density (Vincennes-36648).

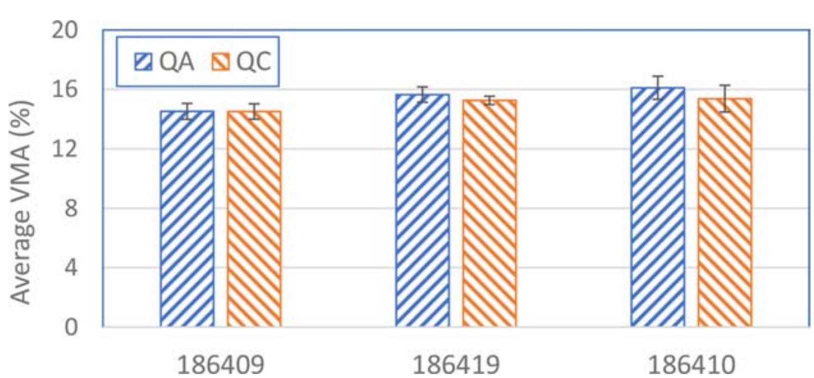


Figure 11.4 Average VMA (Vincennes-36648).

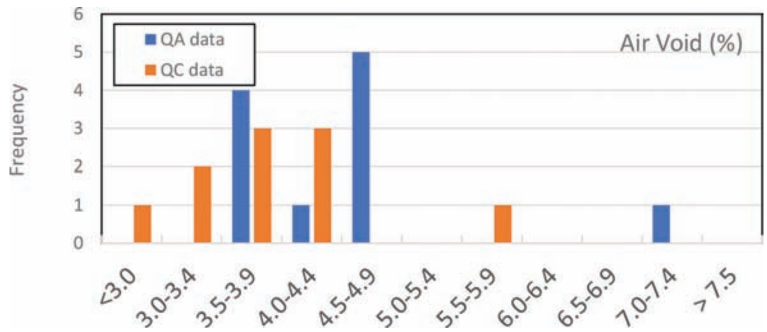


Figure 11.5 Air voids content distribution (Vincennes-36648).

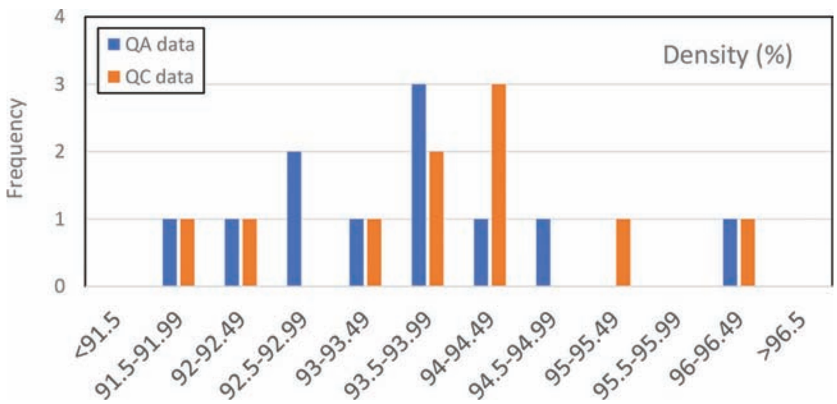


Figure 11.6 Density distribution (Vincennes-36648).

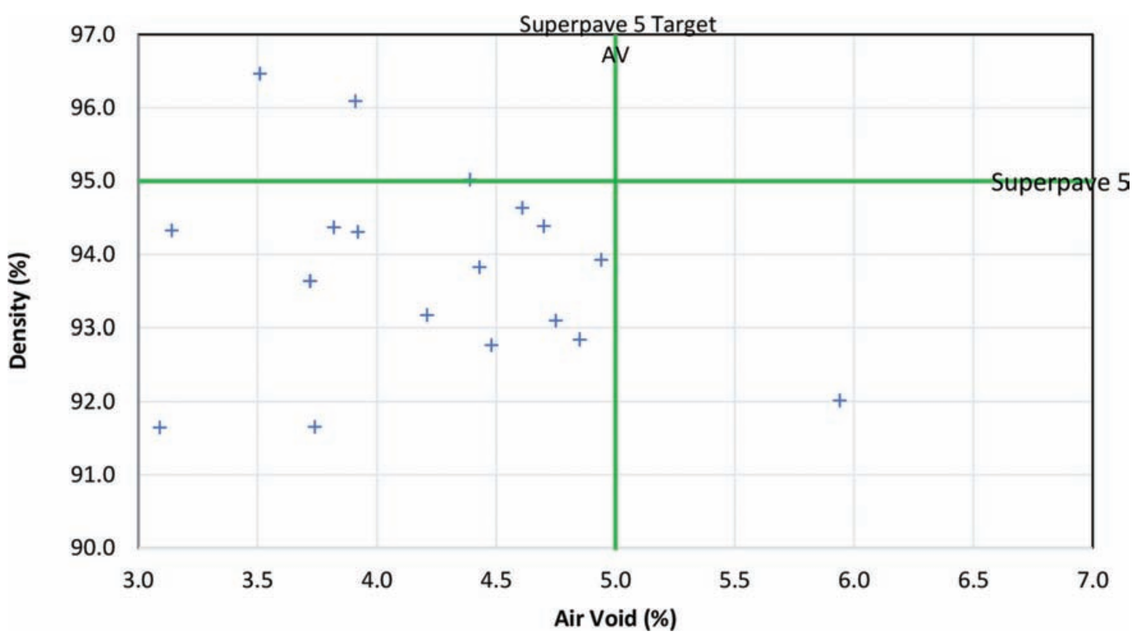


Figure 11.7 Volumetric data summary (Vincennes-36648).

The overall average laboratory air voids content was 4.2%, while the overall average in-place mat density was 93.7%. Figure 11.7 is a plot of all the laboratory air voids and in-place density data. The plot shows that almost all data points lie to the left of 5% air voids content mark, while most of the densities lie between 93% and 95%, slightly below the target of 95%.

12. GREENFIELD (R 30280)

12.1 Overview and Observation Information

The Greenfield District Superpave 5 projects were conducted on the south side of Indianapolis in Marion County. The projects were located on US 31, beginning at Beechwood Lane and ending at Mills Avenue, and on SR 135 from Meridian St. to US 31. US 31 is a north-south roadway with an interchange located at I-465. US 31 is three lanes in each direction and is classified as a Principal Urban Arterial. The project on US 31 can be described as an HMA overlay including functional improvements. The reconstructed SR 135 pavement section is a four-lane road including auxiliary lanes, shoulder sections, and approaches and is classified as a Minor Urban Arterial. The project on SR 135 involved total pavement replacement. The paving projects on US 31 and on SR 135 were approximately 1.83 and 0.53 miles in length, respectively. The current traffic characteristics on US 31 are estimated at 47,855 AADT with 5% trucks. For the SR 135 road section, the current traffic characteristics are estimated at 13,540 AADT with 5% trucks.

INDOT pavement history records show the relevant US 31 section was constructed as a PCC road consisting of two 11-ft. wide lanes in each direction. The roadway was widened to a six-lane section utilizing full depth asphalt in 1976. Pavement cores north of E. Thompson Rd showed that at some point a two-lift asphalt overlay had been placed over a 10-in. jointed reinforced concrete pavement (JRCP) section which transitions to a single asphalt lift overlay as the road approaches the ramps and bridges for the I-465 interchanges. The entire roadway has had several types of overlay treatments between 1951 and 2004. The last known resurface took place in 2004 using an asphalt overlay. Based on pavement cores, full depth asphalt sections range in thickness from 12.25 to 16.75 in. The composite pavement sections encountered had 1.5 to 5.0 in. of asphalt over 7.0 to 14.25 in. of PCC. The exact limits of pavement sections are unknown. The predominant distresses observed were age related top-down cracking and localized sections of fatigue and block cracking. The predominant soil encountered was sandy loam (A-4). The critical soils determined for the US 31 pavement section was sandy loam (A-6) and clay loam (A-7-6). For the SR 135 project, no pavement cores or soil data was reported before the project. However, the Superpave 5 mixtures were placed on a treated subgrade, Type IB (cement only).

The US 31 project used a 9.5-mm surface mixture, 19.0-mm intermediate mixture, and a 19.0-mm base mixture, all Category 3. These mixtures were employed to complete three different typical cross-sections. The first was used to pave south of SR 135 (Thompson Rd) on US 31. This section first had 4 in. of the existing material milled both on the mainline and outside shoulder. Then, a 2.5 in. of a 19.0-mm intermediate mixture were placed and compacted, followed by 1.5 in. of a 9.5-mm surface mixture. The second section, north of SR 135 (Thompson Rd) on US 31 involved milling 1.5 in. of existing asphalt from the mainline and outside shoulder, and then replacing the milled material with a 1.5 in. of 9.5-mm surface mixture. The third typical section was used for full depth asphalt shoulder replacement in pavement sections close to the I-465 interchanges. For this typical section, the existing shoulders were removed and replaced with shoulders comprised of a treated subgrade (Type IC), 6-in. of 19.0-mm base mixture, 2.5 in. of 19.0-mm intermediate mixture, and 1.5 in. of 9.5-mm surface mixture. On US 31, a 25.0-mm Category 3 base mixture was also used to patch and match existing adjacent mainline pavement where required. Finally, the typical replacement pavement section for SR 135 comprised a treated subgrade (Type IC), 6.5 in. of 19.0-mm base asphalt mixture, 3.0 in. of 19.0-mm intermediate mixture, and 1.5 in. of 9.5-mm surface mixture.

The same 9.5- and 19.0-mm surface, intermediate, and base mixtures were used for both projects, with the exception of a PG 76-22 binder in the US 31 9.5-mm surface mixture and a PG 70-22 binder in the SR 135 9.5-mm surface mixture. The 9.5-mm surface mixture was composed of #11 crushed dolomite, #12 crushed dolomite, #24 dolomite sand, 3/8-in. fractured RAP, and baghouse fines. A total of 8,400 and 1,688 tons of 9.5-mm surface mixture were placed on US 31 and SR 135, correspondingly. The 19.0-mm intermediate and base mixtures were composed of #8 stone, #11 stone, #12 stone, #24 stone sand, coarse RAP, fine RAP, and baghouse fines. The US 31 intermediate mixture used a PG 76-22 binder, while the SR 135 intermediate mixture used a PG 70-22 binder. A total of 9,000 and 3,576 tons of 19.0-mm intermediate mixture were placed on US 31 and SR 135, correspondingly. The 19.0-mm base mixture used a PG 64-22 binder and a total of 7,000 tons were required to pave both US 31 and SR 135. Finally, the 25.0-mm base mixture used for patching was composed of #4 stone, #8 stone, #11 stone, #12 stone, #24 stone sand, coarse RAP, fine RAP, and baghouse fines with a PG 64-22 binder. A total of 1,000 tons were reported as used for patching purposes on US 31. The asphalt mixtures were produced in a drum mix facility located at Indianapolis, Indiana, approximately 4 miles from the paving location.

Paving operations on SR 135 took place from September 4 to December 2, 2018. The Purdue team visited the project twice, on September 4 and 27, 2018. On September 4 the bottom lift of the 19.0-mm base mixture was placed on the eastbound lanes. On September 27 the top lift of the 19.0-mm base mixture was placed on the eastbound lanes. The paving train included an MTV, paving machine and two rollers, one for breakdown, the other for finish rolling. The breakdown roller had an operating weight of 13 tons and a compaction width of 79 in. The finish roller had an operating weight of 13 tons and a compaction width of 78.3 in. The breakdown and finish rollers applied 13 and 11 passes, respectively. A similar compaction pattern was observed on both field visits. However, on September 4, breakdown rolling was significantly delayed, to prevent issues attendant to mixture tenderness. QA data shows no significant difference in asphalt mixture properties and aggregate gradation on September 4, but the ambient air temperature high reported for September 4 was 92°F, as opposed to the 71°F for September 27. Presumably, excessive temperatures were experienced by the mixture on September 4. On September 27, the paving operations ran smoothly and without significant delays.

12.2 Data Analysis

The Greenfield project included 9.5-mm surface and 19.0-mm base mixtures. Table 12.1 shows the JMF mixture information.

TABLE 12.1
Mixture information (Greenfield-30280)

Mixture ID	Mixture Type	Course	P_b (%)	VMA (%)	G_{mm}
183412T	9.5 mm	Surface	5.7	16.2	2.524
183413	19.0 mm	Base	5.4	14.7	2.487

Figure 12.1 shows the average binder contents for the Greenfield mixtures. The 9.5-mm surface mixture has a higher binder content than the design binder content, with a higher standard deviation for QC samples. The 19.0-mm base mixture shows a slightly lower binder content than the design binder.

The average air voids contents and mat densities are shown in Figures 12.2 and 12.3. Generally, the average air voids content of all mixtures are lower than the 5% target. A lower difference was observed for the 19.0-mm mixtures, while the average air voids contents for the surface mixture are 4.6% and 4.0% for QC and QA samples, respectively. This may be due to high binder contents in this mixture. The mat density data suggests the mat was slightly under-compacted relative to the 95% target density.

Figure 12.4 shows the average VMA values. The resulting VMA values were close to the 14.7% design VMA for the 19.0-mm mixture. For the 9.5-mm mixture, the VMA values were reported as 16.5% and 16.1% for QC and QA samples, respectively. The design VMA value was 16.2%. A higher than designed binder content likely resulted in the higher VMA.

As seen in Figure 12.5, the air voids content data are distributed from 3% to 7% with the average values of 4.7% and 4.4% for QC and QA samples, respectively. The average air voids are slightly lower than the target of 5.0%.

As shown in Figure 12.6, the reported mat density data are distributed from 91% to 96%. The average mat

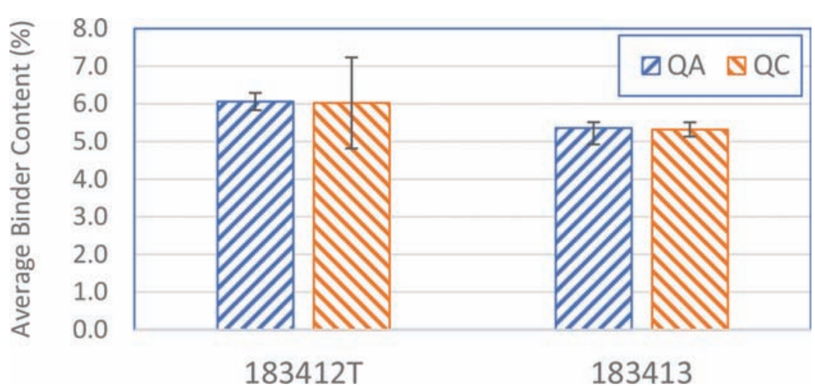


Figure 12.1 Average binder content (Greenfield-30280).

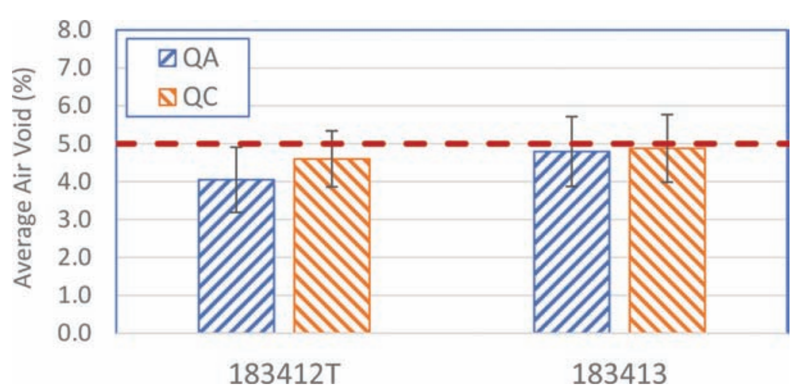


Figure 12.2 Average air voids content (Greenfield-30280).

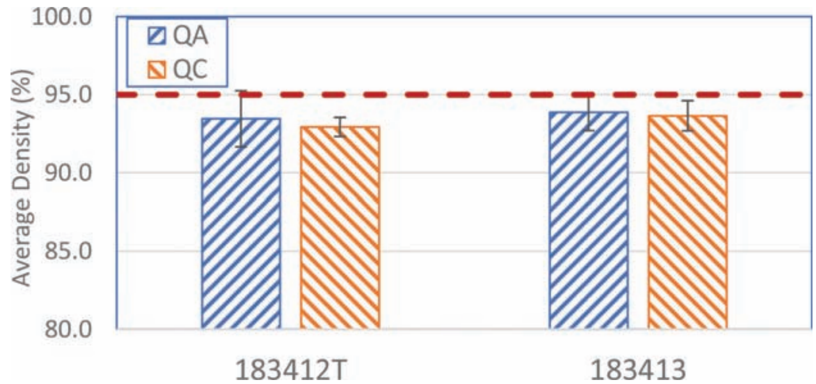


Figure 12.3 Average density (Greenfield-30280).

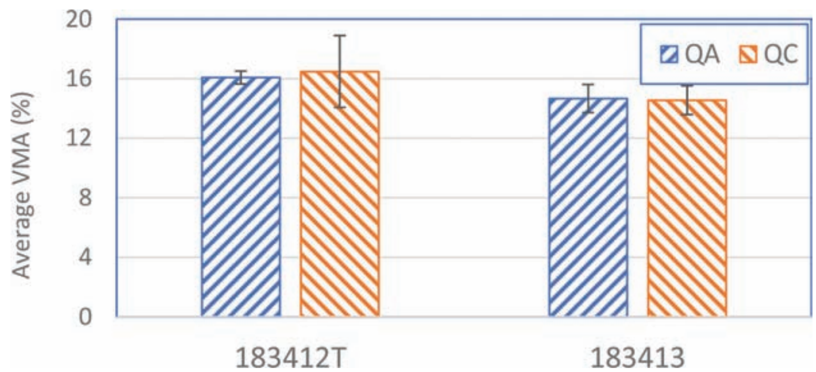


Figure 12.4 Average VMA (Greenfield-30280).

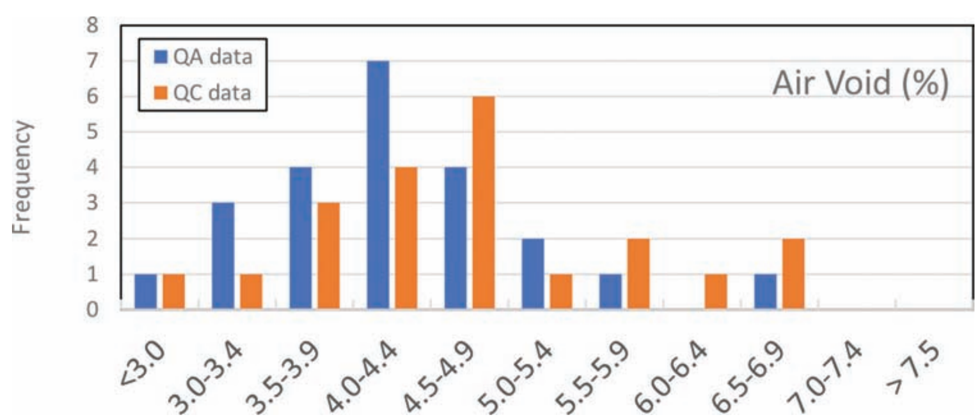


Figure 12.5 Air voids content distribution (Greenfield-30280).

density are 93.2% and 93.6% with standard deviations of 1.37% and 1.52% for QC and QA data, respectively.

The overall average laboratory air voids content for the two projects was 4.6%, while the overall average mat density was 93.45%. Figure 12.7 is a plot of all the laboratory air voids and mat density data. The plot shows most of the mat densities below the 95% target and most of the air voids contents below the 5% target.

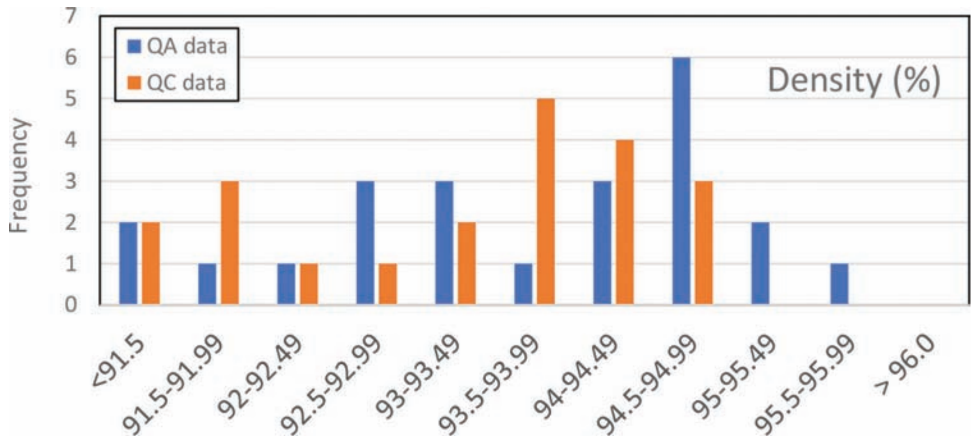


Figure 12.6 Density distribution (Greenfield-30280).

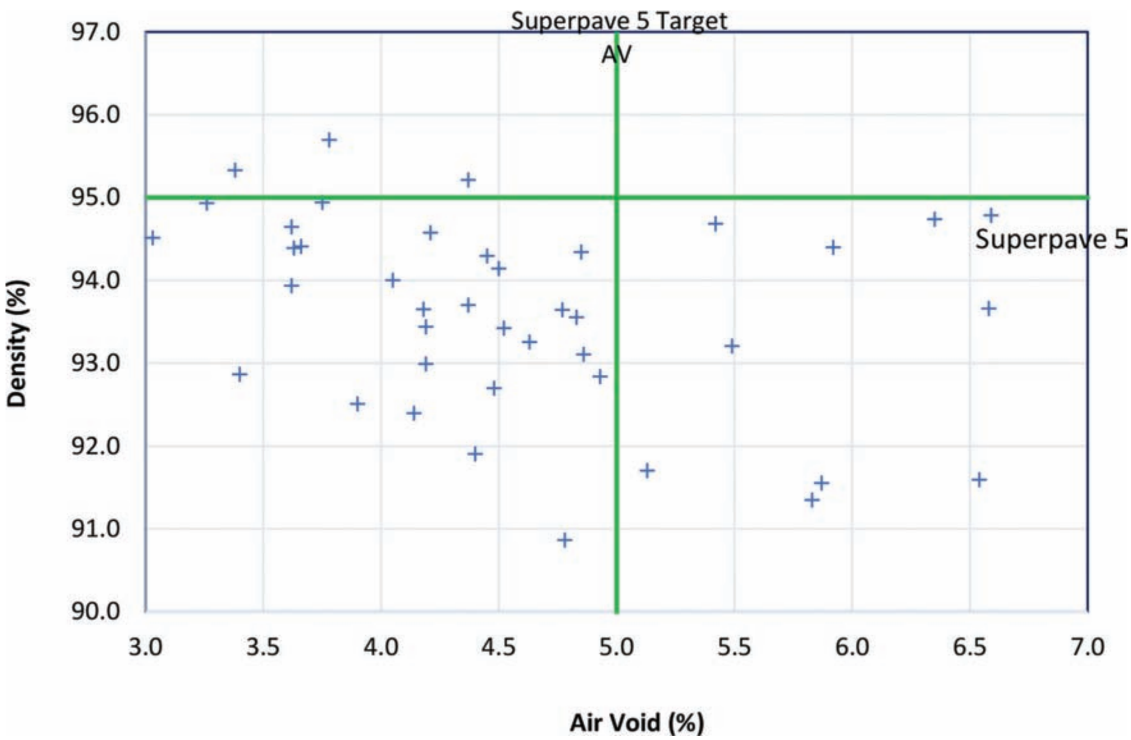


Figure 12.7 Volumetric data summary (Greenfield-30280).

13. COMBINED ANALYSIS

After examining each project individually, the data from all projects were analyzed together to get an overview of the air voids contents and as-constructed mat densities and determine the level of success in using the Superpave 5 mixture design in the projects. A combined total of 380 data points were obtained from QC and QA sampling on the projects.

Figure 13.1 summarizes the laboratory air voids content data, both QC and QA, of the Superpave 5 projects. The data range between 2.5% and 7.5%, with both the median and the average air voids content 5.0%, the target level. As seen in Figure 12.2, on average, Project RS 39353 was successful in achieving the target air voids content of 5%, while Project R 36648 was farthest from the target, achieving and average air voids content of 4.2%, well below the target. With the exception of this one project, the air voids contents were in the range of $5 \pm 0.5\%$. Based on this finding, one could conclude that on average, the projects were effective in achieving the desired level of laboratory air voids content.

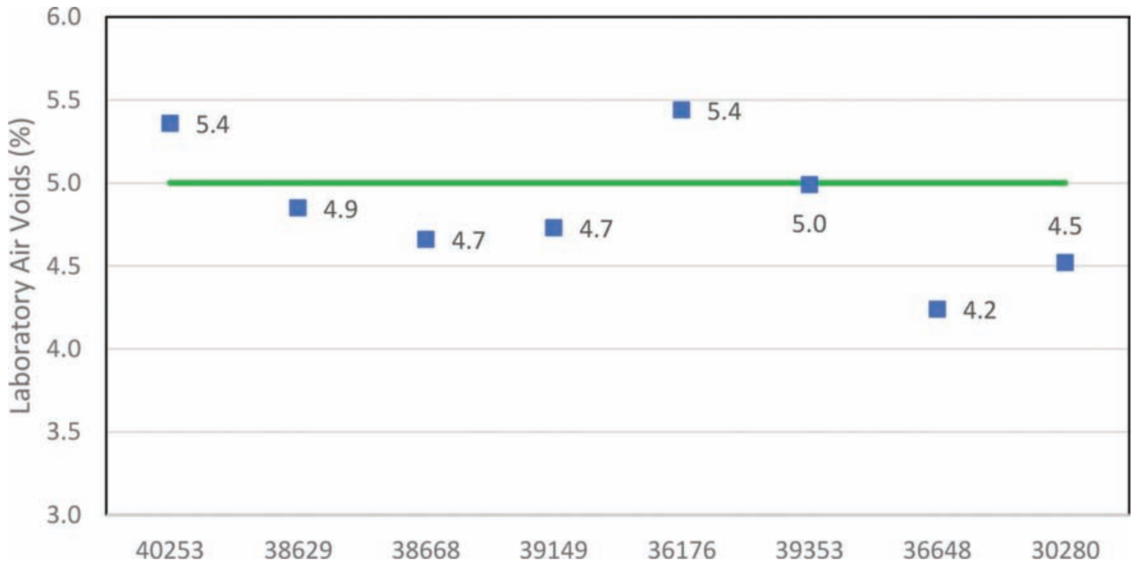


Figure 13.1 Average air voids contents for all projects.

Figure 13.2 Mat density summary for all projects

Figure 13.2 is a summary of the combined QC and QA as-constructed mat densities from the Superpave 5 projects. The density data ranges from 91%–97%, roughly ±4% variability from 95% target value. Project RS 36176 had the lowest average mat density of 91.5%, although this project provided only a limited amount of data. The highest average as-constructed mat density was 94.3%, on Project RS 39353, the project that also reported average laboratory air voids of 5%. Most of the average mat densities are between 93% and 95%, skewing towards former. The average mat density for all projects combined is 93.8%, not much different than what might be achieved with the standard Superpave mixture design method. Based on this finding, it appears the Superpave 5 projects, on average, were somewhat under-compacted with respect to the criteria.

14. SUMMARY AND CONCLUSIONS

For this project, data from nine asphalt paving projects were analysed. Each project was designed and built according to the Superpave 5 mixture design method and attendant specifications. The main objective of the study was to analyse the construction data and report if the specifications were met and if any additional adjustments may be needed to the Superpave 5 mixture design method. Additionally, a literature review of asphalt mixture lift thickness and its effect on asphalt pavement density was completed and recommendations made on the lift thicknesses used by INDOT.

The research team visited five Superpave 5 construction sites, observed the construction process and garnered feedback from the field engineers and contractor personnel about the modified mixture design procedure and any construction concerns. QC and QA data for the projects were supplied to the research team for each of the nine projects. Each set of project data was analysed individually, then all the data combined and analysed. Laboratory air voids content and field density data were compared to the Superpave 5 recommendations. It was found that average laboratory air voids contents achieved for all the projects combined was 5%, which is the Superpave 5 target recommendation. However, the as-constructed mat density for the combined projects combined was determined to be 93.8%, less than the Superpave 5 recommended 95%. Given these findings, the following conclusions are offered:

It is possible to achieve 5% laboratory air voids content during asphalt mixture production when the mixture has been designed at 5% air voids content.

As a whole, the Superpave 5 mixtures reported herein were slightly under-compacted with respect to Superpave 5 recommendations, despite previous trial projects having established that 95% density could be achieved without additional compaction effort beyond that used for conventional Superpave mixtures.

Given that mat densities for the project were lower than anticipated, it is concluded that some additional training is needed for the contractors, in order to help them better design Superpave 5 mixtures that can be field compacted to the 95% target density.

The study findings also indicate what appears to be a possible bias in the QC and QA data. In looking at data distributions, the QC data often appear to have lower laboratory air voids contents and higher as-constructed mat densities than the project QA data.

The t/NMAS ratio data for all the pavement layers constructed under the purview of this study show, that from a design standpoint, INDOT-specified lift thicknesses meet the requirements recommended in the literature.

RECOMMENDATIONS

While the as-constructed mat densities from the nine projects were lower than expected for Superpave 5 mixtures, they were perhaps slightly higher than typical construction densities for conventional Superpave mixtures. It is recommended that field performance of the Superpave 5 mixtures from these projects be monitored over time to examine the impact of the Superpave 5 mixture design method.

Some type of additional training for contractor personnel is recommended. The aim of such training should be to increase their understanding of Superpave 5 concepts and how best to implement the design method in their operation.

Finally, it is recommended that INDOT do a small study to investigate the as-built lift thicknesses of asphalt pavement layers. This data should be collected and examined for compliance with the lift thickness recommendation to ensure the any under-compaction issues are not the result of inadequate lift thickness.

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On March 11, 1937, the Indiana Legislature passed an act which authorized the Indiana State Highway Commission to cooperate with and assist Purdue University in developing the best methods of improving and maintaining the highways of the state and the respective counties thereof. That collaborative effort was called the Joint Highway Research Project (JHRP). In 1997 the collaborative venture was renamed as the Joint Transportation Research Program (JTRP) to reflect the state and national efforts to integrate the management and operation of various transportation modes.

The first studies of JHRP were concerned with Test Road No. 1—evaluation of the weathering characteristics of stabilized materials. After World War II, the JHRP program grew substantially and was regularly producing technical reports. Over 1,600 technical reports are now available, published as part of the JHRP and subsequently JTRP collaborative venture between Purdue University and what is now the Indiana Department of Transportation.

Free online access to all reports is provided through a unique collaboration between JTRP and Purdue Libraries. These are available at http://docs.lib.purdue.edu/jtrp.

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