Asphalt mixture performance and testing

Superpave5: Enhanced pavement durability achieved by changes to design and construction

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Abstract

Throughout most of the world the Marshall method is used to design asphalt mixes. Since the method was developed in the early 1940s, design air voids have been set around four percent (three to five percent). After compaction on the roadway, in-place air voids have been most often targeted to be seven to eight percent. When Superpave was developed in the early 1990s this practice was carried forward. AASHTO specifications for Superpave design call for four percent air voids. Most state DOT specifications target seven to nine percent air voids after compaction on the road. Superpave5 is an adjustment to the mix design system in which the design air void level is five percent. Asphalt content and aggregate requirements remain the same. To develop Superpave5 laboratory design compaction was changed based on engineering properties of in-place Superpave asphalt mixtures. In Superpave5 roadway compaction calls for air voids to be five percent. The main benefit is believed to be a reduced rate of asphalt binder aging that forestalls the occurrence of cracking and extends pavement life. This paper summarizes research that led to changes to the Superpave system. Results of three trial sections are presented and a performance evaluation of the first section at age five years is included. The trials show that Superpave5 mixtures can be compacted to five percent air voids on the road. The performance review shows the effect of lower in-place air voids on aging of the asphalt binder after five years in service and the reduction in crack formation. As well, other performance indicators (ride, rutting) show similar performance to regular Superpave.

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1. INTRODUCTION

Compaction of asphalt mixtures during construction has long been recognized as an important parameter that influences pavement performance. Historically, air voids, both during the design phase and during the in-service phase, have been acknowledged as an important parameter contributing to asphalt performance. The need for air voids is a balance. If design air voids are too low, the resulting asphalt pavement will be susceptible to permanent deformation. If design air voids are too high, the pavement will be susceptible to cracking and disintegration caused by ingress of air and moisture that accelerates aging of the bitumen.

Marshall asphalt design typically uses four percent air voids as a design criterion. During construction the compaction effort is not specified, and typically state highway agencies target eight percent air voids after compaction. The LCPC method of asphalt design generally has a range of five to eight percent for design and a field target compaction of five percent. This paper discusses changes made to the Superpave asphalt design method to allow compaction to field five percent air voids.

2. BODY OF THE PAPER

BACKGROUND

Historically, asphalt has been designed at four percent air voids and constructed to a nominal in-place air void content of eight percent. This concept has existed since development of the Marshall method of mixture design in the 1940s (Roberts et al [1]). It was generally accepted that mixtures thus designed and initially compacted would densify under traffic to achieve the design air void level.

When Superpave asphalt design was developed in the mid-1990s the same concept of air void levels was carried forward (Kennedy et al [2], McDaniel et al [3]). The AASHTO standard for Superpave mixture design, (AASHTO Specification M323 [4]), specifies design air voids should be four percent. Compaction guidelines suggest a target of 93.0 percent of theoretical maximum density (G_{mm}), seven percent air voids, at the end of construction (Cominsky [5]).

In the 1970s the Laboratoire Central des Ponts et Chaussées (LCPC) developed a method of asphalt design based on a principle that compaction during design should match compaction during construction (Moutier [6]). The mix design system was set up to control both laboratory compactive effort (number of gyrations of the LCPC gyratory compactor) and the field compactive effort (number of passes of prescribed pneumatic-tired roller) (Moutier, F., [7]). LCPC has documented that there is little or no increase in density under traffic during the pavement in-service life (Moutier [8]).

The LCPC method specifies a range of design air void content (CEN [9]). Generally, designers target toward the lower end of the range, typically five percent air voids. Under this system, asphalt pavements have a more consistent, lower air void content than pavements constructed in North America. The desire to change Superpave to achieve 95 percent density is based on the potential to slow the rate of bitumen aging for better durability.

The LCPC method of design is based on standardized laboratory compaction and standardized construction compaction. Typically, application of the standard rolling train will yield the desired density. Superpave has a standardized laboratory compaction (design number of gyrations of the Superpave gyratory compactor) but does not have a standardized construction compaction effort. Instead, a target density is given, and the amount of compaction effort is varied to achieve the specified density.

Since Superpave asphalt design was implemented in the mid-1990s, asphalt pavement performance has improved. In Indiana the average life of pavements designed with the Marshall system was 12 years. After implementation of the Superpave asphalt design system the average life has increased to 16 years. One should not conclude that the difference in pavement life is exclusively the result of switching to Superpave.

Compaction specifications were changed at the same time as Superpave asphalt design implementation. During the era of Marshall design in Indiana typical in-place air void contents were nine to eleven percent. When Superpave asphalt design was implemented, compaction specifications were changed to an average of 92 percent density, in-place air void levels of eight percent. Then in the early 2000s the Indiana Department of Transportation (INDOT) changed compaction specifications from an average value to a statistical specification based on Percent Within Limits (PWL). Full pay was obtained for achieving 90 percent within limits (90 PWL). The specification is based on a distribution using only a lower limit, Lower Quality Limit (LQL). The LQL was set at 91.0 percent. With typical variability (standard deviation of 1.5 percent) the average compaction required to achieve 90 PWL is about 93.2 percent, nominally, seven percent air voids.

Following implementation of Superpave asphalt design, rutting of asphalt pavements has become a rare occurrence. Rut resistance is controlled by aggregate properties and compaction. In Indiana, the implementation of Superpave did not force changes to the coarse aggregates being used. Quarried aggregate had been used and natural aggregate (crushed gravel) was not commonly used. Indiana's quarried aggregate meets the Superpave coarse aggregate properties, no change in coarse aggregate was needed. However, Superpave implementation did change fine aggregates use. The Fine Aggregate Angularity test changed the amount of natural sand that could be used. Marshall designs commonly contained 25 percent but Superpave designs typically have 10 percent or less. During implementation of Superpave reduced natural sand improved rut resistance and increased density improved both rut resistance and aging resistance.

Adjusting Superpave Design to Improve Compactability

To increase density, one option is simply to increase the target, in this case, from 93 percent to 95 percent. This would require additional compactive effort during construction. Assuming it is possible and practical to increase compaction simply by increasing roller passes, the resulting asphalt will have a higher rutting resistance. But, rutting resistance of current mixtures is adequate; increased resistance is not necessary.

The objective was to adjust Superpave asphalt design (Superpave 4) to allow compaction to 95 percent G_{mm} using similar amounts of construction compactive effort (Superpave 5). A research program done to establish the laboratory design compactive effort (number of design gyrations) was reported on previously (Huber [10]). The recommended design compactive effort for Superpave 5 is 30 gyrations. Changes to Superpave 4 specifications include air voids increase from 4.0 percent to 5.0 percent, VMA criteria increase by 1.0%, Voids Filled with Bitumen change from 65 – 75 percent to 60 – 70 percent.

CONSTRUCTION OF TRIAL SECTIONS

Three trial sections were constructed using the proposed changes to Superpave 4. Each trial was part of an existing paving contract. Information is shown in Table 1. Trial 1 and 3 are 9.5-mm Nominal Maximum Aggregate Size (NMAS) surface mixtures. Trial 2 is a 19.0-mm NMAS intermediate mixture. Trial Section 1 and 2 were designed using 30 gyrations. Trial 3 was designed with 50 gyrations since INDOT had decided that as a standard.

Trial Section 1

The first trial project was constructed in 2013 on State Road 13 (SR 13) in northern Indiana. It is a two-lane, narrow-shoulder collector road servicing light manufacturing. The existing surface was milled, and two lifts of asphalt were placed. The Superpave 4 asphalt had N_{design} of 100 gyrations and Superpave 5 used 30 gyrations. The aggregate blend included steel slag, a hard aggregate to resist carbide tips of horseshoes from horse-drawn vehicles that use the road.

Table 1 Summary of Trial Sections for Superpave 5

Property	Trial 1, SR 13	Trial 2, Georgetown Rd	Trial 3, U.S. 40
Date	June 2013	December 2014	November 2016
Average Annual Daily Traffic	13,410	20,000 (est.)	17,790
Percent Heavy Trucks	19%	5% (est.)	5%
Design Gyrations	30	30	50
Nominal Maximum Aggregate Size, mm	9.5	19.0	9.5
Thickness, mm	38	76	38
Quantity, tonnes	1190	1010	2450
Recycled Asphalt Content, %	0	38	14.1
Reclaimed Asphalt Shingles, %	7	0	2.9
Bitumen Replacement, %RAP / %RAS	0 / 21	37 / 0	12 / 9
Bitumen Content, %	5.4	4.8	7.1

Table 2 Summary of Trial Section Quality Assurance Test Results for Superpave 5

	Superpave 4			Superpave 5		
	Bitumen Content, %	Air Voids, %	Core Density, $\%G_{mm}$	Bitumen Content, %	Air Voids, %	Core Density, $\%G_{mm}$
Trial Section 1, U.S. 13						
Average	5.2	2.9	91.4	5.2	4.0	96.9
Std. Dev.	0.11	1.05	1.13	0.17	0.67	0.74
Trial Section 2, Georgetown Road						
Average	4.7	4.4	92.2	4.6	5.5	95.8
Trial Section 3, U.S 40						
Average	6.5	4.8	93.2	6.8	5.9	95.2
Std. Dev.	0.12	0.72	1.11	0.40	1.17	0.81

The mixing plant and road construction operation is typical for asphalt in the U.S. A counterflow drum mix plant produced asphalt at 200 tonnes per hour. A material transfer device was used to load asphalt from trucks into the paver. Two vibratory steel rollers were used for compaction and the same rolling pattern was used for the Superpave 5 asphalt as for the Superpave 4 asphalt. The normal system of Quality Control (QC) and Quality Assurance (QA) was done on the project. Three sets of tests (sublots) were done on the 1,190 tonnes of asphalt. From each sublot two cores were taken, a total of six. QA tests are performed by the INDOT and are shown in Table 2.

Bitumen content for the mixtures was on target and the same for both Superpave 4 and Superpave 5. Air voids were about one percent below target for both asphalt mixtures. Compaction of Superpave 4 was lower than the 93 percent target. For Superpave 5, compaction was above the target value of 95 percent. Experience from this trial included knowledge that Superpave 5 asphalt could be produced with normal variability with normal asphalt plant controls. Also, Superpave 5 asphalt could be placed using the same equipment and compacted using the same rollers and rolling pattern as the Superpave 4 asphalt.

Trial Section 2

The second trial project was constructed in the late fall of 2014 on Georgetown Road, a major collector road in the City of Indianapolis. The road carries a large volume of traffic with low truck percentage. The research asphalt was part of the 19.0-mm NMAS intermediate layer. Superpave 5 asphalt was designed using 30 gyrations. The Superpave 4 project was designed with 100 gyrations.

One unknown about Superpave 5 asphalt was the potential for tenderness, asphalt moving laterally instead of compacting. Tenderness was not observed in the SR 13 project; however, the steel slag aggregate is very angular and less likely to show tenderness.

The Georgetown Road project used limestone and was placed thicker, 75 mm instead of the normal 63 mm. If tenderness was a potential issue, then this project might allow tenderness to be exhibited but no signs were present. The asphalt behaved very similar to the Superpave 4 asphalt.

The Georgetown Road trial project was smaller in mass, 1,010 versus 1,190 tonnes, and in area because the thickness was greater. As a result, this trial contained only two sub-lots of material. QA test results are listed in Table 2.

Bitumen content for the mixtures was near target. Superpave 4 mixture was 0.1 percent higher than design and the Superpave 5 mixture was 0.2 percent below the design. For both mixtures air voids were slightly high, 0.4 percent for the Superpave 4 and 0.5 percent for the Superpave 5 but within typical variability. Compaction for the Superpave 4 mixture was about 0.8 percent below the target of 93 percent. Compaction for the Superpave 5 mixture was 0.8 percent higher than the target.

Trial Section 3

The third trial project was constructed in November 2016 on U.S. 40, a composite pavement of concrete overlain by asphalt. The project included milling the surface and placing a new layer of 9.5-mm NMAS asphalt. The road is an urban arterial that carries 17,790 vehicles per day with five percentage trucks. The Superpave 5 asphalt was designed using 50 gyrations. The decision had been made to use 50 gyrations for all mixtures above the category of 3 million ESALs and 30 gyrations for mixtures with lower ESALs.

Table 3 Summary of Volumetric Property Standard Deviations for Trial Section 3

	Standard Deviation for Combined QC and QA Tests		2003 Study Standard Deviation	2003 PWL Quality Limits
	Superpave 5	Superpave 4	Superpave 4 (9.5-mm NMAS)	Superpave 4 (All Sizes)
Air Voids, %	1.06	0.57	0.87	+ / - 1.30
VMA, %	0.50	0.65	0.80	+ / - 1.00
Bitumen Content, %	0.40	0.11	0.21	+ /- 0.30
Compaction	0.82	0.98	1.52	-2.00

Table 4 Tests Done to Forensic Cores from Test Section 1

Property	Measurement	Test Method
Bulk Specific Gravity	G_{mb}	AASHTO T 166
Theoretical Maximum Specific Gravity	G_{mm}	AASHTO T 209
Bitumen Content	Percent	AASHTO T 164
Air Voids	Percent	AASHTO T 269
Bitumen Recovery	Percent	ASTM D5404
Bitumen Performance Grade	PG-HT, PG-LT	AASHTO M 320
$T_{critical}$	ΔT_c	AASHTO M 320
Permeability	cm/day	Florida Method of Test FM 5-565

This trial section was significantly larger than the first two. The objective was to quantify variability of the properties INDOT uses for acceptance and compare to variability of the same properties in Superpave 4 asphalt. Average QA values and standard deviation are listed in Table 2. Asphalt content for the Superpave 5 asphalt is slightly higher than the Superpave 4 asphalt. Air voids were 0.8 percent higher than the target value for both mixtures and compaction were near the target of 93 percent and 95 percent respectively.

In 2003 INDOT began using statistical specifications for asphalt acceptance based on calculating Percent Within Limits (PWL) for lots of material. One lot of material contains five sublots. Lower Quality Limit and Upper Quality Limit were set for each property based on typical standard deviation. A two-year database of contractor tests (QC) and DOT tests (QA) was used to set the Percent Within Limits specification.

A summary of standard deviation from Trial Section 3 (combined QC and QA) and the 2003 database is shown in Table3. Note the 2003 Quality Limits were set at approximately one and a half standard deviations from the target. Two of the Superpave 5 standard deviations, air voids and bitumen content, are higher than the 2003 study.

Air voids are calculated using bulk specific gravity of the compacted asphalt (G_{mb}) and theoretical maximum specific gravity (G_{mm}). Intrinsically, there is no reason why measurement of these two properties should be more variable for Superpave 5 asphalt than for Superpave 4. The data set from Trial Section 3 is much smaller than the 2003 study, so there is less certainty that the data are accurate representations of true standard deviation. Therefore, it was concluded that the air void standard deviation for Superpave 5 is not representative.

Likewise, when considering the control of bitumen content, the asphalt plant measures aggregate mass and controls the flow of bitumen independent of the mixture being produced. No reason exists for higher variability for Superpave 5 and, as a result, it was concluded to be the result of the small dataset.

PERFORMANCE OF TRIAL SECTIONS

The trial sections have been in service for six, four and three years respectively for Trial Sections 1, 2 and 3. A detailed review of Trial Section 1 was done in 2018 (age five years) and a performance review of Trial Section 3 was done in 2019 (age three years). Asphalt in Trial Section 2 is in the second layer from the surface and no discernible difference in performance can be seen.

Trial Section 1

In March 2018 surface condition of Trial Section 1 was evaluated. Three sets of six cores were taken to determine properties of the asphalt and bitumen of the Superpave 5 and Superpave 4 sections. Tests were performed as listed in Table 4.

At each location Cores 1 and 2 were used to measure two values of theoretical maximum density (G_{mm}) and were then combined for extracting and recovering the bitumen. Extraction was done according to AASHTO T 164 using dichloromethane in a centrifuge extractor. The bitumen performance grade for high temperature and low temperature was done according to AASHTO M 320 (AASHTO [4]) except that no short-term aging (Rolling Thin Film Oven Test) or long-term aging (Pressure Air Vessel) was done prior to testing. The bitumen had already been subjected to construction temperature and needed no short-term aging. Also, the asphalt had been in service for five years and no additional long-term aging was needed.

High temperature grade of the recovered bitumen was determined as the temperature that $G^*/\sin\delta$ fails the criterion of 2.2 kPa. Low temperature grade was measured at -12°C and -18°C and a fail temperature was determined for m-value (m) and stiffness (S). The failing temperature for stiffness and m-value were used to calculate $\Delta T_{critical}$. Delta $T_{critical}$ is defined as the difference in fail temperature for stiffness minus and m-value.

On average, bitumen from the Superpave 4 locations had a grade of PG100-16 and from the Superpave 5 locations PG94-21. The grade of new bitumen used on SR 13 was PG70-22. Reclaimed bitumen from post-consumer roofing shingles (RAS) contributed approximately 20 percent of the total bitumen content. Continuous grade of bitumen from RAS or the PG70-22 was not measured but both the Superpave 4 and Superpave 5 bitumen contain the same proportion of the two. At the time of construction in 2013 recovered bitumen had a continuous grade of PG88-12.

Air voids, as shown in Table 5, were calculated according to AASHTO T 269 using the average G_{mm} from Cores 1 and 2 and individual core G_{mb} values. Asphalt permeability occurs from interconnected air voids that allow passage of water (water permeability) or air (air permeability). Interconnected air voids are influenced by the NMAS, gradation (coarse versus fine) and compaction. Both Superpave 4 and Superpave 5 asphalt are the same NMAS and gradation is only slightly different. Therefore, permeability should be related mainly to compaction (air voids). When air voids are low, permeability is low because the air voids are not interconnected. As air voids increase, a threshold is reached, and voids start interconnecting. Then, small increases cause a significant increase in permeability.

Water permeability results are listed in Table 6 and the relationship to air voids is shown in Figure 2. When air voids are low, permeability is low and remains low even as air voids increase. At about 7.5 percent air voids permeability increases very rapidly. Note that permeability of Superpave 5 and Superpave 4 overlap at 5.5 to 7.0 percent.

Table 5 Air Voids of Cores from SR 13

	Superpave 4			Superpave 5		
Core	**Location 1**	**Location 2**	**Location 3**	**Location 1**	**Location 2**	**Location 3**
1	7.7	7.1	8.2	5.8	5.9	3.4
2	7.7	5.7	7.9	4.6	5.9	3.6
3	8.1	6.0	7.6	3.6	6.4	3.0
4	9.1	5.8	6.8	4.5	7.1	3.3
5	8.4	5.9	8.2	4.4	6.3	3.3
6	8.2	5.6	7.3	3.1	6.9	3.5
Average	8.1	6.0	7.7	4.3	6.4	3.4
Ave Cores 1 & 2	7.7	6.4	8.0	5.2	5.9	3.5

Table 6 Permeability of Cores from SR 13

	Superpave 4			Superpave 5		
Core	**Location 1**	**Location 2**	**Location 3**	**Location 1**	**Location 2**	**Location 3**
1	10.4	0.6	9.9	5.4	0.5	0.7
2	12.0	0.6	18.1	1.9	0.5	3.0
3	10.3	0.5	49.3	0.9	6.1	0.5
4	18.1	0.5	5.4	1.4	2.9	3.6
5	0.0	0.6	31.4	0.5	2.9	3.7
6	5.7	0.6	57.5	2.8	0.5	2.9
Average	9.4	0.6	28.6	2.1	2.2	2.4

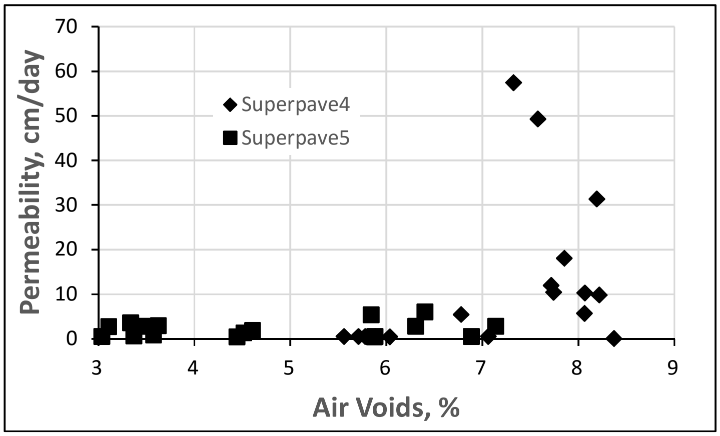

Figure 1 Relationship of Permeability and Air Voids for Superpave 4 and Superpave 5 Asphalt on SR 13

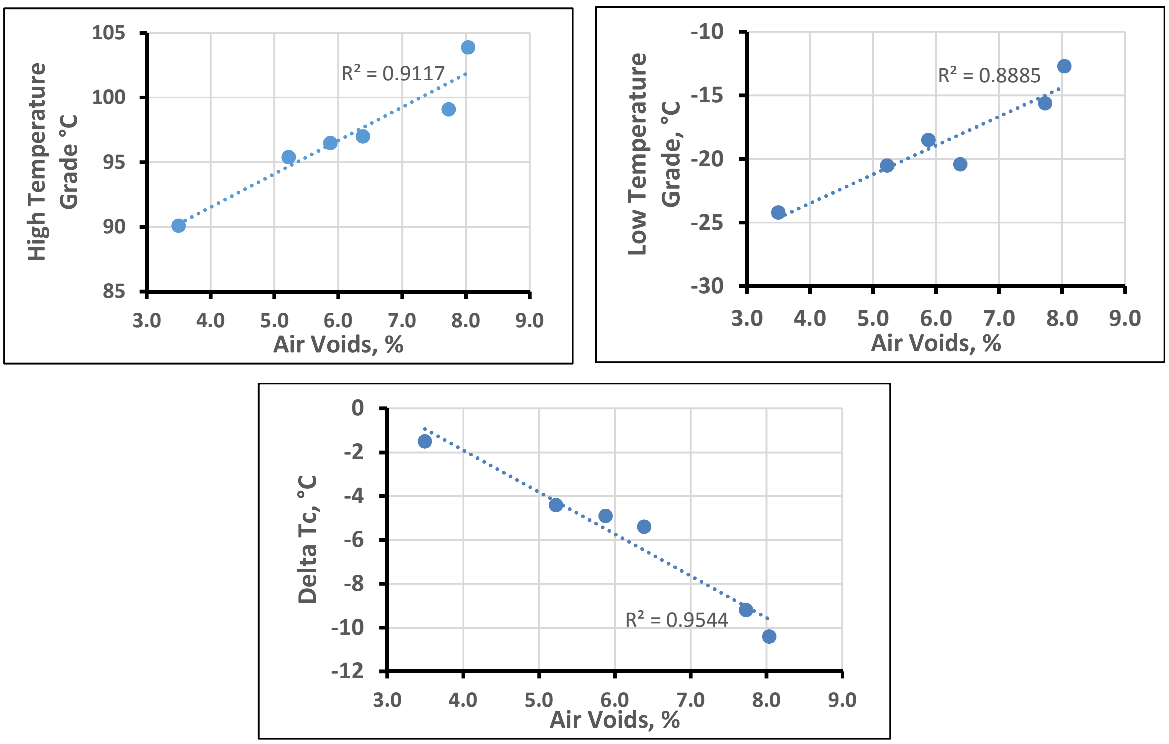

Figure 2 Relationship of Recovered Bitumen Grade and Delta T_c to In-Place Air Voids

The relationship of bitumen high temperature grade, low temperature grade and ΔT_c with air voids at the each of the locations is shown in Figure 3. Air void values used in these plots are the average air voids of Cores 1 and 2 from Table 5. There is a strong correlation between asphalt binder properties and in-place air voids. The coefficient of determination for high temperature grade, low temperature grade and ΔTc are 0.91, 0.89 and 0.95 respectively.

The 2013 rehabilitation project removed the surface asphalt and placed two new layers of asphalt. The lower replacement layer was Superpave 4 asphalt. Superpave 5 asphalt was used only in a portion of the surface layer. General observations showed that crack sealing had occurred as is shown in Figure 4. Transverse reflective cracking has occurred throughout the entire project and the amount is about the same for both Superpave 4 and Superpave 5 asphalt. However, the Superpave 4 asphalt shows considerable surface cracking between the reflective cracks. Figure 4 shows fine cracking in the Superpave 4.

A pavement condition van collected pavement smoothness (International Roughness Index, IRI) and rut depth (mm). Rut depth is minor (3.3 mm for Superpave 4 and 3.0 mm for Superpave 5 sections). Ride is smooth (0.68 m/km for Superpave 4 and 0.44 m/km for Superpave 5).

Figure 3 Observation of Cracking of Superpave 4 (left) and Superpave 5 (right) Asphalt

Figure 4 Westbound lanes, Trial Section 3, Superpave 5 (left lane) and Superpave 4 (right lane)

Trial Section 3
The U.S. 40 project was milled to remove the existing surface and replaced with a new asphalt layer. The existing pavement is concrete pavement overlain with hot mix asphalt. The trial sections consisted of 2.9 km of roadway five lanes wide. An equal amount of Superpave 4 and Superpave 5 asphalt was placed.

In February 2019 the project was just over two years old and a visual survey showed little difference in performance on most of the project. However, in some of the Superpave 4 mixture, cracking is present as shown in Figure 5. There Reflective cracking is not suspected, and it appears that the Superpave 4 mixture will have more cracking than the Superpave 5.

Early in 2018 INDOT decided to implement Superpave 5. Rather than constructing additional trial sections, in which a portion of a regular Superpave 4 project was converted to Superpave 5, twelve projects were bid as Superpave 5. The visual observations on U.S. 40 confirmed the decision to begin implementation.

In 2018 twelve projects were tendered for Superpave 5 using specifications based on data from Trial Section 3. In January 2019 INDOT changed their standard specifications and in September 2019 onward all asphalt will be tendered as Superpave 5.

SUMMARY AND FINDINGS

Superpave 5 asphalt is designed with five percent air voids and intended for compaction to 95 percent density (five percent in-place air voids). This paper has described the concept of LCPC mix design applied to Superpave (Superpave 4), development of Superpave 5 and construction and performance of trial sections.

- Superpave 5 asphalt requires a reduced amount of gyrations (N-design) during design. The research showed that Superpave 4 asphalt designed with 100 gyrations was equivalent to Superpave 5 asphalt designed with 30 gyrations.
- Three trial sections were constructed between 2013 and 2016. No change in plant procedures was required, and compaction with the same equipment and number of passes produced approximately 95 percent density.
- Variability in asphalt properties (air voids, bitumen content and VMA) and compaction is similar for Superpave 5 asphalt as for Superpave 4 asphalt and is similar to a 2003 database used to set limits for Quality Acceptance (PWL).
- Permeability is directly related to in-place air void content. Aging of bitumen was directly related to the air void content (indirectly to permeability). After five years the Superpave 5 bitumen had aged less than the Superpave 4 bitumen. High temperature grade was six degrees lower and low temperature grade was five degrees lower.
- Superpave 4 asphalt on State Route 13 and U.S. Highway 40 had more cracking than the comparable Superpave 5 asphalt. Delta T_c of the recovered asphalt binder on SR 13, a measure of cracking susceptibility, varied in direct proportion to the in-place air void content for both Superpave 5 and Superpave 4 asphalt.
- On State Route 13 the smoothness (IRI) and rut depth after five years are approximately equal for Superpave 5 and Superpave 4 asphalt.
- INDOT changed their standard specifications to Superpave 5 asphalt from September 2019 onward.

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Annex

1. BACKGROUND FOR THE ANNEX

The purpose of this paper was to show the development of asphalt design and the approach to design air voids and in-place density (compaction). The Marshall method typically uses four percent (range of three to five percent) for design and these mixtures are usually compacted to in-place air voids of approximately seven or eight percent. The Superpave method of asphalt design carried this concept forward. The mix design method developed in France by the LCPC in the 1970s, in contrast, used a principle of the design air voids being similar, or the same, as compaction air voids, approximately five percent.

In 2012 research was done to adapt the LCPC design philosophy to the Superpave method of asphalt design. This paper documented the construction and performance of trial sections that were built using the modified Superpave method, referred to as Superpave5 to highlight the change in design air voids from four to five percent. The original Superpave method is referred to as Superpave4 based on the design air voids being four percent.

Three trial sections are discussed in the paper, two of which are surface asphalt mixtures constructed in 2013 and 2016. The third section was an intermediate mixture constructed in 2014. As of 2019, the date of authorship of this paper, no discernible performance observations could be made on the 2014 project. The 2013 project included extensive forensic evaluation as outlined in the paper. An informal performance evaluation was included for the 2016 project.

As noted in the paper, the Indiana Department of Transportation began a phased implementation of Superpave5 in 2018 based on favourable findings of the forensic evaluation and the improved performance of the 2013 and 2016 projects. After the two-year phase-in, Superpave5 became the standard process for asphalt design in 2020. All projects constructed in 2020 were designed using Superpave5.

In this paper, performance of the 2013 project was evaluated in March 2018 and performance of the 2016 project was evaluated in February 2019. An updated informal evaluation of cracking performance was done in February 2021 and is included in this annex.

2. EVALUATION OF THE 2013 PROJECT

As noted in the paper, mix design of both the Superpave4 and Superpave5 asphalt contained a high percentage of heavily oxidized asphalt binder creating a blend of asphalt binder with a very high performance grade. Note that although allowed in 2012, current specifications have restricted the allowable percentage of bitumen from shingles.

Also as noted in the paper, at the time of construction recovered bitumen graded as PG88-12 when subjected only to additional long-term aging of the pressure air vessel (PAV). Bitumen recovered in 2018 was not subjected to any additional aging. Bitumen from the Superpave4 sampling sites graded PG100-16 on average and from the Superpave5 sampling sites as PG94-21 on average. As a comparison to typical reclaimed bitumen in Indiana, a 2011 study of bitumen from 33 reclaimed asphalt stockpiles had an average grading of PG90-11 [1]. Hence, the bitumen in the 2013 project had a high temperature stiffness almost four times the stiffness of typical reclaimed bitumen.

An unintended consequence of selecting this 2013 project for a Superpave5 trial is an accelerated evaluation of performance difference. Figure 3 in the paper is a comparison photo taken in 2018. The most significant difference is environmental-type block cracking. A site inspection done in February 2021 (an additional three years in service) show a continued differentiation in cracking performance.

In addition to accelerated block cracking, the Superpave4 mixture has suffered more severe damage from impact loading. Although not highlighted in the paper, this project is in an area with a significant amount of Amish population who use horses for transportation. Wear (loss of material from impact of horseshoes) causes rutting and reduction of pavement life. Although horse traffic was not quantified as part of this investigation, it is reasonable to assume that traffic going into the town (Superpave4 in the northbound lane) is approximately equal to that returning to farms (Superpave5 in the southbound lanes). Figure 1 shows horseshoe wear is significantly more excessive in the Superpave4 asphalt as compared to the Superpave5 asphalt. Also apparent is the difference between environmental cracking in the right lane (Superpave4) and the left lane (Superpave5).

Figure 1: 2013 Trial Project Performance after Eight Years, Superpave5 in Left Lane, Superpave4 in Right Lane

3. EVALUATION OF THE 2016 PROJECT

A field inspection of the 2016 project was done in February 2021. A preventive maintenance (appears to be micro-surfacing) has been applied. It appears to be about a year old and was likely done in the summer of 2019. Some crack sealing, at the longitudinal joints has also occurred since the last field inspection in February 2019.

Figure 2 shows a 2021 view of the same location shown in Figure 4 of the paper. The longitudinal cracks visible in Figure 4 are no longer visible.

Figure 2: Location of Longitudinal Cracks in 2016 Project After Application of Pavement Preservation Treatment

REFERENCES

[1] Beeson, M., Prather, M., and Huber, G., "Characterization of Reclaimed Asphalt Pavement in Indiana: Changing INDOT Specifications for RAP", Transportation Research Board Meeting, Washington, D.C. January 2011