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Quality control/quality assurance testing for longitudinal joint density and segregation of asphalt mixtures

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HIGHLIGHTS

- Evaluate available test methods for longitudinal joint quality control.
- Develop specifications to ensure the longitudinal joint with proper performance.
- Evaluate the effect of segregation on longitudinal joint density performance.

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ABSTRACT

Longitudinal joint quality control/assurance is essential to the successful performance of asphalt pavement and it has received considerable amount of attention in recent years. Five paving projects were selected for sampling and evaluation in Iowa. For each project, joint quality is compared with regard to the "center" of the pavement mat (6′ right of joint). Field densities and permeability test were made. Cores were obtained for subsequent lab permeability, density and indirect tensile (IDT) strength testing. Asphalt content and gradations were also obtained to determine the joint segregation.

In general, this study found that methods providing the most reliable measurements of joint quality are the AASHTO T166, AASHTO T331 (CoreLok) density tests and the permeability test by Karol-Warner Permeameter. The minimum required joint density for quality control should be around 90.0% and 88.5% of theoretical maximum density based on the AASHTO T166 and AASHTO T331 method respectively. Based on various mix design and longitudinal joint construction methods, the joints show differences in asphalt content and level of segregation. Results of this study indicate that poor quality of longitudinal joint should be a combination of segregation, asphalt content variation and insufficient density.

1. Introduction

Several methods were generally used to measure and quantify the quality of longitudinal joint construction. These include the field and in-lab permeability test, nuclear/non-nuclear density test and core density test. In recent years, a number of apparatuses have been developed to measure the permeability value of an HMA mixture and among which the NCAT field Permeameter and the Karol-Warner (K-W) in-lab Permeameter are the most popular ones. Previous studies in Arkansas, New England and Tennessee have had similar conclusions for the use of permeability test on the longitudinal joint [1–3]. They all found that the joints have significantly higher permeability compared to adjacent mats and the use of infrared joint heater can greatly reduce the longitudinal joint permeability. Utilizing the two permeability testing devices, permeability criteria are determined based upon the percent within limit (PWL) of pavement air voids by Missouri Department of Transportation (DOT). The upper specification criteria for using the NCAT Permeameter and K-W Permeameter are 1560×10^{-5} cm/s and 530×10^{-5} cm/s, respectively [4]. In another study conducted in the National Center for Asphalt Technology (NCAT), the critical permeability infers to the point at which a pavement becomes excessively permeable [5]. However, none of a research currently has proposed quality control criteria using Permeameters for longitudinal joint construction. In addition to permeability tests, density measurement is also a key indicator used to judge the quality of a HMA pavement. The most widely used core density

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testing method is the AASHTO T-166 method. An extensive review was conducted on longitudinal joint construction and specification documents proposed by various transportation agencies and the density at the joint are all generally recommended to be no more than 2–3% lower than the density specified in the lanes away from the joint [6]. Recently, another method using the CoreLok device via AASHTO T-331 method has been employed by many researchers and transportation agencies. They found that the CoreLok system tends to result in lower densities than the AASHTO T-166 method especially for lower density samples as is typical of joint cores [1]. The development of nuclear and non-nuclear density gauges offers an alternative way to measure the pavement density non-destructively. Williams and Hall [7] evaluated the effects of gauge model, temperature, gauge orientation and the present of sand using the PaveTracker and PQI non-nuclear gauges. They found that gauge orientation, moisture, sand and debris can significantly affect the reading of the two types of gauges.

To construct a sound longitudinal joint, mitigation of segregation is important. As stated by AASHTO [8] the longitudinal joint area has a higher probability of being segregated. This commonly occurs from the augers not being run at sufficient speeds on the paver, allowing the coarse aggregates to roll to the outside of the mat. In addition, in order to avoid joint segregation during the paving process the auger and tunnel should be extended within 12–18 in. of the end gate so the material can be carried, and not pushed out to the joint. Several testing methods have been generally used to detect and measure the segregation of HMA. These include permeability test and nuclear/non-nuclear density test. Williams et al. [9] found that the nuclear moisture/density gauge is capable of accurately measuring both asphalt content and density in a dry pavement condition. They also pointed out that the permeability test is only successful in detecting coarse segregation but not fine segregation. This is mainly because the permeability test depends more on the interconnected nature of void volume rather than simply the percent of voids. Fine dense-graded mixtures would have sufficiently low permeability that, even when moderately segregated, there is little to no statistical difference in permeability measurements. Larsen and Henault [10] used density profiles obtained from a PaveTracker non-nuclear density gauge to quantify the level of segregation in Connecticut. However, they found that the spatial variation in density alone from the density gauge cannot distinguish the differences in segregated and low density area. Extracted asphalt content and gradations are also commonly used as a destructive way to determine segregation. As reported by Cross and Brown [11], the pavement segregation has strong correlation with the percent passing #4 sieve, while Williams et al. [9] used the sieve size that can separate the mix gradation into approximately equal portions to define the fine and coarse segregation. However, both of the study pointed out that segregation results in significant asphalt content variation which increases from very coarse to very fine [9,11].

2. Test plan and procedure

Five projects are selected for sampling and evaluation in this project study with each one represents a typical longitudinal joint construction technique as shown in Table 1. All five construction techniques are commonly used in Iowa. A summary of the five projects location, longitudinal joint construction type, lift thickness, surface mix type, and mix design are all listed out in Table 1. The route numbers for the five projects are designated as the project names in this study for simplicity. Brief discussions for each construction method are as follows:

The butt joint applies the first roller pass with the wheel on the hot lane and overlapped onto the cold lane by about a 150 mm (6 in.), while the modified butt joint (hot pinch) applies the first roller pass with the wheel on the hot lane and about 150 mm (6 in.) away from the joint. The hot pinch has the potential to push HMA in the hot lane towards the joint during the initial roller pass. Milling and filling joint construction method include first milling a single lane, overlay that lane, and then mill the adjacent lane. Confinement can be formed during both the paving process of the cold and hot lanes by the milling and filling method. Temperature is always considered as the key in pavement construction. It is generally believed that higher compaction temperature can help increase compaction of the mix at the joint and improve the bond between the cold lane and hot lane. Higher temperature can also increase the flow ability of the mix and reduce segregation. The infrared joint heater by reheating the joint to around 230 °F before compaction is reported to be very effective [3,12] and more detailed temperature and thermal conductivity analysis for infrared joint heater can be found in the literature [12]. With the same idea, longitudinal joint paved in WMA is believed to have a tight and better compaction than HMA [13].

The test plan contains two parts: field testing and laboratory testing. Field testing and sampling consisted of obtaining pavement density by the PaveTracker non-nuclear gauge, field permeability measurements using the NCAT Permeameter and extracting pavement cores from six random locations for each project. In each random selected test location, field tests were done on both the pavement longitudinal joint and the mid-section of the hot lane (about 6′ right of longitudinal joint). Therefore, this results in testing a total number of 12 field locations and corresponding 12 core extractions from each project. Field density measurements using PaveTracker non-nuclear gauge can be greatly affected by water; therefore, they were performed firstly at each location. Once the PaveTracker density measurements were completed, NCAT permeability tests were made at the same location. After the pavement surface course is totally cooling down, core samples were taken at the same places where the field tests were performed. The core samples are from 4 to 6 in. in diameter and the thickness equals to the lift thickness of the surface course. Finally, these cores were transported to the Bituminous Materials Laboratory at the Iowa State University for further testing.

The following tests were performed on each field core samples in the laboratory: (1) voids analysis, (2) in-lab permeability, (3) indirect tensile strength and (4) determination of asphalt content and gradation. The void analysis includes the bulk specific gravity tests in accordance with AASHTO-T166 and the AASHTO T-331 method by the CoreLok® system. Karol-Warner (K-W) Permeameter was used for the in-lab permeability test based on the ASTM PS129 method. Upon completion of the laboratory density tests, core samples were tested for IDT strength following the AASHTO T-322 procedure. The joint core samples are loaded along the direction of the longitudinal joint so that failure could occur along the joint and the IDT strength at the joint can be obtained. Finally, the broken core samples were used to determine the asphalt content and gradation by the ignition method according to the AASHTO T-308 and AASHTO T-30 procedures respectively. Calibration factors were used in the ignition method from the cold-feed gradations to provide acceptable results.

3. Test results and analysis

For each test method, the test results were firstly compared to see whether they are capable of detecting the density, permeability and tensile strength differences on longitudinal joint and 6′ right of the pavement joint (on pavement mat). Graphical comparisons for all projects are shown in Figs. 1–3.

On the basis of the results comparison, the following conclusions are drawn:

Table 1
Project summaries.

Projects	US-6	IA-148	IA-13	I-35	US-61
County	Iowa	Cass	Linn	Clark	Lee
Construction method	Butt joint (HMA)	Butt joint (WMA)	Butt joint + joint heater	Milling and filling	Butt joint + hot pinch
Mix type	3 M surface 1/2 L-4	1 M surface 1/2 L-4	3 M surface 1/2 L-4	30 M surface 1/2 L-2	3 M surface 1/2 L-4
Binder content	4.7	5.3	5.7	5.4	6.1
Lift thickness (in.)	1.5	1.5	1.5	2	2
Gradation					
3/4 in.	100	100	100	100	100
1/2 in.	93	91	97	93	97
3/8 in.	87	87	86	84	88
#4	64	64	64	69	65
#8	42	44	50	50	46
#16	30	32	41	33	32
#30	21.5	18	30	20	20
#50	8.4	7.3	18	10	8.2
#100	5.5	4.1	8.8	5.3	4.5
#200	3.7	3.5	3.7	3.5	3.7

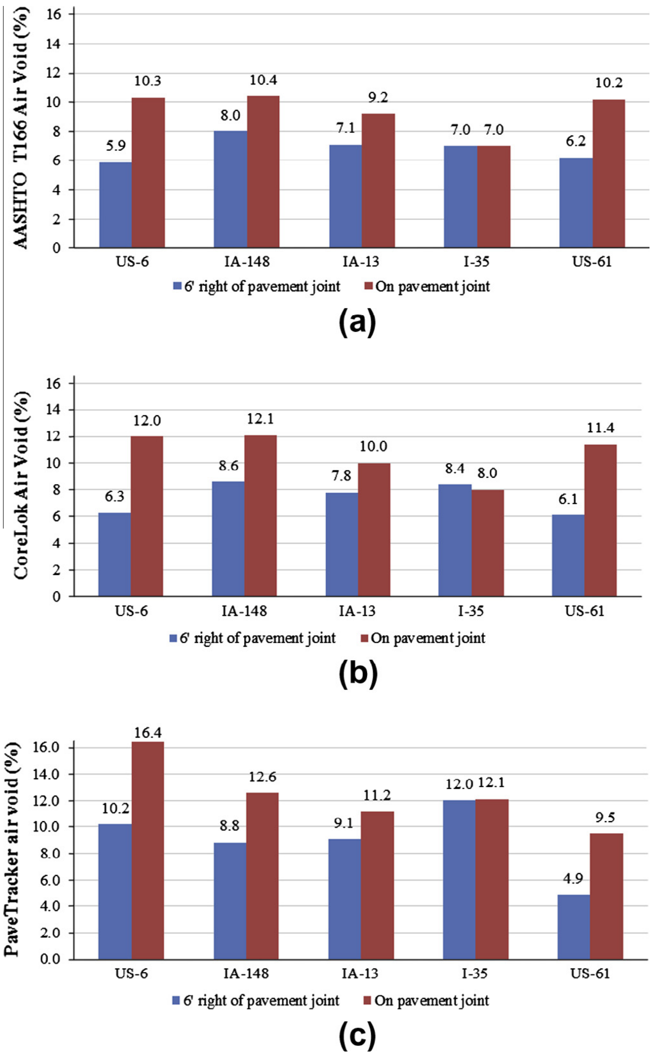

Fig. 1. Comparison of mean air void values using different density testing methods: (a) AASHTO T166 method, (b) CoreLok method and (c) PaveTracker method.

From Fig. 1a and b, both laboratory measures of density demonstrate the ability to detect significant differences in density with proximity to the joint. The CoreLok method did in general yield lower density values and thus higher air void values than AASHTO T166. On the longitudinal joint, the air void gap between CoreLok and AASHTO T166 methods becomes even larger.

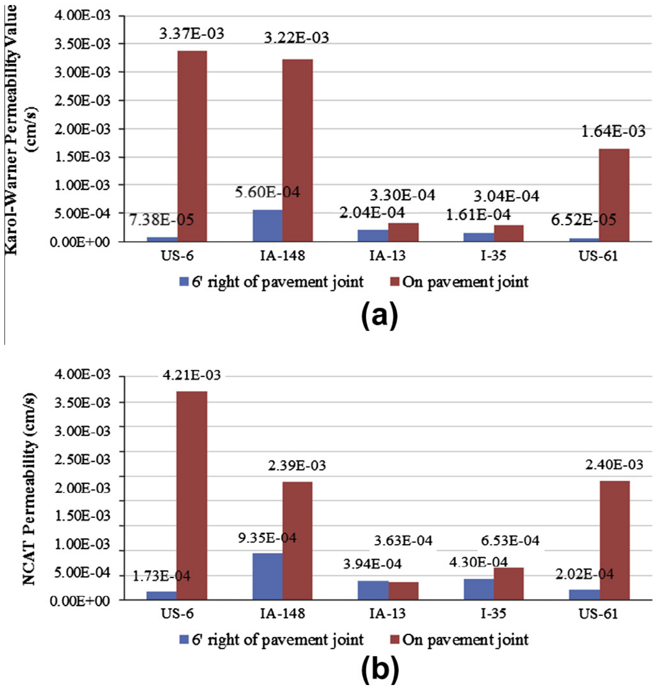

Fig. 2. Comparison of mean permeability values using different permeability test methods: (a) K-W Permeameter and (b) NCAT Permeameter.

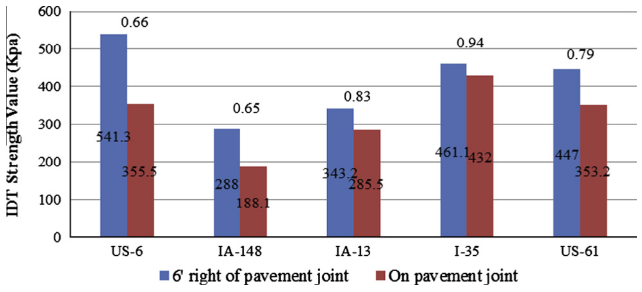

Fig. 3. Comparison of mean IDT strength values.

While the PaveTracker non-nuclear gauge demonstrates the ability to detect the differences in density between the longitudinal joint and 6′ right of the joint as shown in Fig. 1c, it gives far less accurate air void values comparing with the laboratory density tests. Difference pavement temperature, moisture and surface texture could be the reasons. In addition, during the field testing it was observed that improper compaction can result in uneven longitudinal joint and this would make the density gauge placed on it not fully touching the joint surface.

Although it is not intended to compare which longitudinal joint construction method performs the best in this study, it is quite evident that the IA-13 and I-35 projects using joint heater and milling and filling technique give significantly lower lab and field permeability and air void values than the other projects. One important observation from Fig. 2 is that the NCAT Permeameter provides either higher or lower values comparing with the K-W Permeameter. A problem of the NCAT Permeameter is that it is not easy to form a totally watertight seal and if water leakage happens the device would overestimate the permeability value. On the other hand, putting too much sealant material to seal the Permeameter could lead the sealant entering into the 6″ testing area and thereby blocking a portion of the test area. This would underestimate the field permeability value. Therefore, the test method is very operational dependent.

In Fig. 3, the mean IDT strength on pavement mat is higher than that on pavement joint for all of the projects. The ratio values of the longitudinal joint to pavement mat IDT strength are also listed above the columns in Fig. 3. Without any special treatment, the butt joints paved in HMA and WMA (US-6 Project and IA-148 Project) exhibit the lowest ratio values. It is recommended that the ratio value should not be lower than 0.8. However, more tests should be performed to support the idea. With various mix design the IDT strength are quite different. The projects IA-148 and IA-13 give lowest mean IDT strength value. This is because the project IA-148 is paved with WMA with 1.8% of water injection while the IA-13 project contains many fine aggregates, which leads to the thinnest film thickness. Therefore, without comparison on pavement mat IDT strength on longitudinal joint alone cannot be used for quality control purpose.

Of the testing methods discussed above, AASHTO T166, AASHTO T331 (CoreLok) and ASTM PS126 K-W permeability test methods are considered to be the most reliable measurements to quantitatively determine the density and permeability of longitudinal joints. Determinations of critical in-place air void and permeability values on the longitudinal joint are presented in Figs. 4 and 5. The critical air voids is considered to be the point at which the two lines tangent to the regression line intersect. At the intersecting point of these two lines, a bisecting line was then drawn to the egression line. The point at which the bisecting line hits the regression line was defined as the critical point for air voids and permeability. Although the method gives different critical air voids for the CoreLok (AASHTO T331) and AASHTO T166 as seen in the figures, it illustrates close critical K-W permeability values, which is around 1.5e−03 cm/s as shown in the two figures. The minimum required longitudinal joint density is around 90% of theoretical maximum density based on the AASHTO T166 method. In the same approach, the graphical representation show that the critical air voids is around 88.5% of theoretical maximum density according to AASHTO T331 (CoreLok) method. In addition, Figs. 4 and 5 shows that the CoreLok method has a better correlation than the AASHTO T166 method with a higher goodness of fit (R^2). On the other hand, the AASHTO T166 method is much less sensitive in the high air void region and provides more scattered results, where both fine segregation and coarse segregation are also detected on the longitudinal joint as follows.

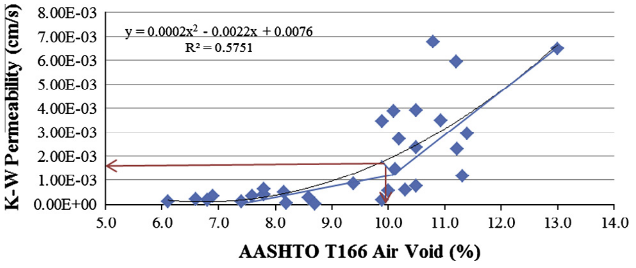

Fig. 4. Selection of critical permeability and CAASHTO T166 air voids values on joint.

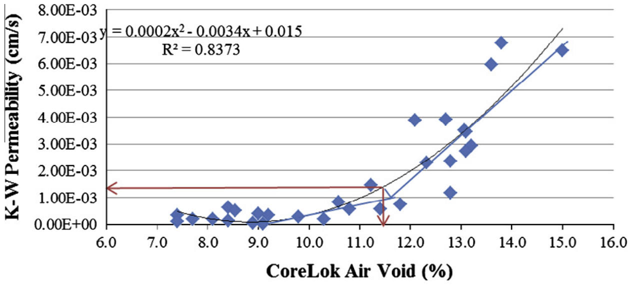

Fig. 5. Selection of critical permeability and CoreLok air voids values on joint.

Asphalt content and gradation of the field samples were determined according to the AASHTO T-308 and AASHTO T-30 procedures, respectively. The fineness modulus is also calculated, since the calculation of fineness modulus can serve as an overall gradation descriptor by combing the gradation data on each sieve. Finally, all of these data including the permeability, density and IDT strength data used the JMP software for the one way analysis of variance (ANOVA) to determine whether there are statistically significant differences between the paired data for on pavement joint and mat values. A 95% confidence was used in all cases. If statistically significant differences are evident, plus (+) and minus (−) signs are provided as further descriptors. A (+) sign indicates that the test values on pavement joint are significantly higher than that on pavement mat, while a (−) sign conveys that the test values on joint sample are significantly lower than those on pavement mat. Gradation results on each sieve are taken as the value retained on each sieve for comparison. Gradation results on each sieve are taken as the value retained on each sieve for comparison. Therefore, a positive sign (+) for the gradation change indicates that significantly more aggregates are retained respective sieve for the longitudinal joint samples. Based on the results of the analysis shown in Table 2, the following observations are found. Based on the results of the analysis shown in Table 2, the following observations are found.

Project US-6 (HMA butt joint): The (+) positive signs on fineness modulus and percent passing the #4, #8, #30 and #50 sieves indicate that the longitudinal joint gradation is significantly coarser than the pavement mat. In addition, permeability, density and IDT strength tests are clearly able to detect the lower density and coarse segregation (coarser gradation) at the longitudinal joint.

Project IA-148 (WMA butt joint): A decrease in asphalt content and the gradation on key sieves (#8 and #16) are coarser than the pavement mat is a typical pattern for coarse segregation. Permeability, air void and IDT strength measurements are clearly able to detect the lower density and coarse segregation at the longitudinal joint.

Project IA-13 (Infrared joint heater): significant differences in fineness modulus, percent passing the #16, #30, #50, #100 and #200 sieves are identified. The (−) negative signs reveal that the longitudinal joint gradation is significantly finer than the pavement mat. Although significantly lower density is detected at the longitudinal joint by AASHTO T166 and AASHTO T331 methods, the joint heater creates air voids lower than the recommended air void requirement. Fine segregation may also help reduce the

Table 2
Summary of one-way ANOVA test results.

	US-6 Joint vs Mat	IA-148 Joint vs Mat	IA-13 Joint vs Mat	I-35 Joint vs Mat	US-61 Joint vs Mat
NCAT permeability	Significant (+)	Significant (+)			Significant (+)
K-W permeability	Significant (+)	Significant (+)			Significant (+)
Corelok air voids	Significant (+)	Significant (+)	Significant (+)		Significant (+)
AASHTO T166 air voids	Significant (+)	Significant (+)	Significant (+)		Significant (+)
PaveTracker	Significant (+)	Significant (+)			Significant (+)
IDT strength	Significant (−)	Significant (−)	Significant (−)		
Asphalt content		Significant (−)			Significant (+)
% Pass 1/2″ change				Significant (+)	
% Pass 3/8 ″change					
% Pass #4 deviation	Significant (+)			Significant (+)	Significant (−)
% Pass #8 change	Significant (+)	Significant (+)			Significant (−)
% Pass #16 change		Significant (+)	Significant (−)	Significant (−)	Significant (−)
% Pass #30 change	Significant (+)		Significant (−)	Significant (−)	
% Pass #50 change	Significant (+)		Significant (−)	Significant (−)	
% Pass #100 change			Significant (−)	Significant (−)	Significant (−)
% Pass #200 deviation			Significant (−)	Significant (−)	Significant (−)
Fineness modulus	Significant (+)		Significant (−)		Significant (−)
Segregation type	Coarse	Coarse	Fine	No	Fine

permeability and neither the NCAT nor the K-W Permeameter shows statistical difference in the measurement.

Project I-35 (Milling and Filling): Although significant differences were detected by gradation, a consistent trend was not present for all of the sieves, which is not a typical pattern for gradation segregation. Actually, the one-way ANOVA test result shows that longitudinal joint has a more gaped gradation compared with the pavement mat. No statistical difference is found in the overall gradation comparisons and asphalt content. In addition, none of other tests (density, permeability and IDT strength tests) have shown significant differences. This tends to indicate that the longitudinal joint formed by milling and filling has slight or no segregation with close density and stiffness values to that of the pavement mat.

Project US-61 (Hot pinch): Higher asphalt content is present at the longitudinal joint by pinching and more fine aggregates are seen on the joint. In addition, significantly lower density and IDT strength are clearly shown at the longitudinal joint by the ANOVA test. Although permeability on joint and pavement mat shows significant difference, fine segregation may help reduced permeability, which can be seen in Fig. 2a on the comparison of permeability test.

In general, the last row in the table summarized the different longitudinal joint segregation type for each project that has been discussed above. Both fine and coarse segregation have been identified along the longitudinal joint and further investigation to see whether segregation affects longitudinal joint density or not. An indicator sieve is selected that can be used to represent the overall gradation segregation difference on the longitudinal joint and pavement mat. The indicator sieve is defined as follows: (1) the selected sieve should be closest to the 50/50 passing and (2) the percent passing on the sieve should also have significant difference between pavement mat and joint. As can be seen from Table 2, No. 8 sieve is considered as the indicator sieve for the project US-6 and IA-148, No. 16 sieve is used for the IA-13 project, #4 sieve is used for the I-35 project, and #8 sieve is selected for the US-61 project. The relationship between the gradation segregation change on the indicator sieve and the CoreLok air voids are further shown in Figs. 6–9. The goodness of fit (R^2) for the relationship between the air void and gradation deviation on the indicator sieve may reflect out whether segregation can greatly affects the longitudinal joint density or not. The project I-35 is not involved in the analysis since the preliminary investigation has shown that it appears to have no segregation. As can be seen, the R^2 values for projects US-6, IA-13 and US-61 are around 0.4–0.5 showing that some correlation does exists between density variations and segregations. The correlation is relatively low, however, the trend shows that the air voids content increases on both coarse segregation and fine segregation and the coarse segregation showing a higher rate of change compared with fine segregated joints, which agrees with that in the work of others [9]. Keeping in mind only one indicator sieve is selected to correlate with the air voids, which

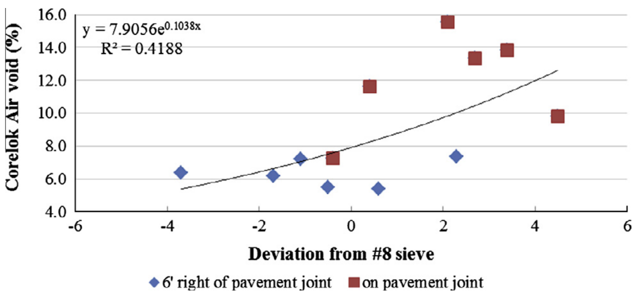

Fig. 6. Air voids vs gradation change on the indicator sieve for the US-6 project.

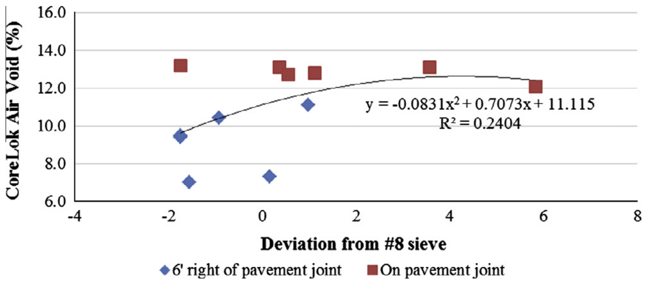

Fig. 7. Air voids vs gradation change on the indicator sieve for the IA-148 project.

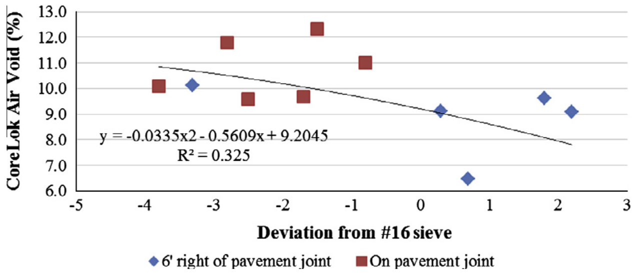

Fig. 8. Air voids vs gradation change on the indicator sieve for the IA-13 project.

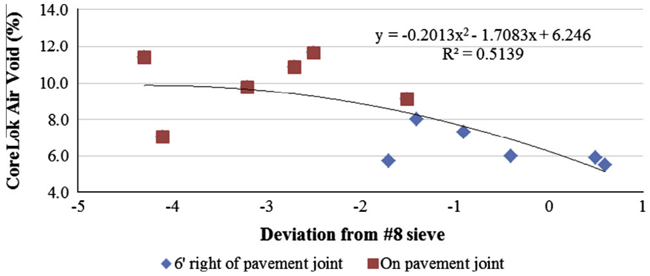

Fig. 9. Air voids vs gradation changes on the indicator sieve for the US-61 project.

may lead to a lower R^2 value. In addition, it also indicates that although segregation can greatly affect longitudinal joint performance, it may not be the only factor. Spatial variations in density for the longitudinal joint could be also the result of lack of roller compaction and other construction issues (mix temperature in compaction, longitudinal joint alignment, etc.), which cannot be controlled during field experimental test. The R^2 for the project IA-148 is poor. This could be mainly because the longitudinal joint density decrease on IA-148 project is more related to the deficiency in asphalt content.

4. Summary

Premature longitudinal joint failures are a result of a combination of low density, low tensile strength, high permeability and segregation. Five paving projects were selected for sampling and evaluation in Iowa. Based on the work conducted in this study, the following conclusions and recommendations can be made.

1. The CoreLok method (AASHTO T-331) in general yields lower density values and thus higher air void values than AASHTO T-166. Greater differences in the density results are seen for the samples at the longitudinal joint.
2. The PaveTracker density gauge and NCAT Permeameter can distinguish the difference between longitudinal joint and pavement mat. However, they are not recommended as viable tools for quality control and assurance purpose.
3. It is recommended that the minimum required longitudinal joint density that the contractor to achieve should be 90.0% and 88.5% of theoretical maximum density based on the AASHTO T166 and CoreLok (AASHTO T331) methods, respectively.
4. The Karol-Warner Permeameter is recommended for use in quality control testing, the strong relationship between the Karol-Warner and air voids results illustrates that the Karol-Warner could be successfully used to measure the permeability of field core samples. A corresponding Karol-Warner in-lab permeability criteria identified according to the minimum required longitudinal joint density is 1.50e-03 cm/s.
5. IDT strength test is reliable and the ratio values for the longitudinal joint to pavement mat IDT strength is recommended no less than 0.8 for quality assurance purpose.
6. All of the projects appear to have segregation at the longitudinal joint except for the one using milling and filling method. Based on various mix design and joint construction methods, the joints show quite different changes in asphalt content and types of segregation as compared with the pavement mat. Results of this study indicate that the lower density of longitudinal joints could be a combination of gradation segregation, significant asphalt content variation and a lack of field compaction.
7. Neither the butt joint nor infrared joint heater could provide confinement during the joint compaction process. Hot pinch of the longitudinal joint by pushing extra material for compaction near to the joint could help achieve better joint density, however, fine aggregates and excess of asphalt could be stacked over the joint. The method of milling and filling one lane at a time is feasible to avoid the unsupported edge and a confinement has the potential to avoid the spread of aggregation segregation.

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