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EFFECT OF AGGREGATE GRADATION ON MEASURED ASPHALT CONTENT

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ABSTRACT

It is necessary to control the asphalt content closely in hot mix asphalt (HMA) mixes to obtain optimum serviceability and durability. However, coarser mixes (binder and base courses) made with larger maximum particle-sized aggregate tend to segregate, The resulting variation in the aggregate gradation of the sampled HMA mix can significantly affect the measured asphalt content. The objective of this research was to evaluate the effect of aggregate gradation on the measured asphalt content.

Actual mix composition (asphalt content and gradation) data from a major interstate paving project was obtained and analyzed. A total of 547 binder course and 147 wearing course mix samples were obtained behind the paver and subjected to extraction analysis, A substantial amount of segregation was observed in the binder course mix which provided the opportunity to correlate the aggregate gradation with the measured asphalt content.

Some of the deviation in the measured asphalt content of the binder course mixes from the job mix formula (JMF) was determined to be the result of the change in gradation of the mix from the JMF. The percentages of material passing the 4.75 mm (No. 4) and 2.36 mm (No. 8) sieves are correlated with measured asphalt contents. For segregated binder course mixes evaluated in this study, equations were developed to adjust the measured asphalt content to account for the change in gradation from the JMF as measured on the 12.5 mm (1/2 inch) and either 4.75 mm (No. 4) or 2.36 mm (No. 8) sieves.

EFFECT OF AGGREGATE GRADATION ON MEASURED ASPHALT CONTENT

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INTRODUCTION

Asphalt content must be closely controlled in hot mix asphalt (HMA) mixes to obtain optimum serviceability and durability. A HMA pavement can ravel and/or crack if it is deficient in asphalt content by as little as 1/2 percent, whereas 1/2 percent excessive asphalt content can cause flushing and rutting.

Quality control (QC) and quality assurance (QA) of HMA pavements generally require the measurement of asphalt content in HMA mixes during production using either a standard extraction test or a nuclear asphalt content gauge. However, the measured value can vary from test to test because of material, sampling, and testing variability. In recent years, the material variability has been reduced substantially by the use of automated HMA facilities. Testing proficiency can be improved through training. Obtaining a representative HMA sample for testing still remains a problem either because of segregation or ineffective sampling/splitting techniques. When coarser mixes (binder and base courses) made with larger maximum particle-sized aggregates are involved, the sampling variation can overshadow the material variation and testing variation. Coarse HMA mixes tend to segregate. The coarse aggregate fraction in the HMA mix holds less asphalt cement by weight compared to the fine aggregate fraction, Segregation causes the proportions of coarse and fine aggregate particles (therefore, the gradation) to vary in HMA samples and thus affect the measured asphalt contents. There is a need to evaluate the effect of aggregate gradation on measured asphalt content so that an adjusted asphalt content which is closer to the asphalt content actually incorporated in the HMA mix, can be ascertained.

PROJECT DETAILS

The test data for this study was obtained from a major 4-lane interstate paving project in Pennsylvania. This rehabilitation project involved 50.8mm (2 inches) of Pennsylvania ID-2 binder course (a dense graded binder mix with 38,1 mm or 1 1/2 inch maximum aggregate size) and 38.1 mm (1 1/2 inches) of Pennsylvania ID-2 wearing course (a dense graded wearing mix with 12.5mm or 1/2 inch maximum aggregate size). The job-mix formulas (JMF) for the binder and wearing course mixtures are given in Tables 1 and 2, respectively.

Northbound (NB) and southbound (SB) lanes were paved with separate pavers. Since the mix acceptance or QA samples were obtained behind each paver separately, the test data has been reported and analyzed separately for NB and SB lanes. Pennsylvania Department of Transportation (PennDOT) has a statistically based end result specification for HMA pavements which requires obtaining loose mix samples behind the paver at random locations. The entire loose mix is scraped out of a well defined area (usually 229mm x 229mm or 9 inches x 9 inches) at the selected random location to minimize segregation due to sampling operation. Five loose mix sublet samples are obtained for each lot consisting of about 500 Mg (550 tons). These samples are sent to PennDOT central laboratory for extraction to determine the mix composition. Roadway cores are also obtained after compaction and sent to the central laboratory for determining the pavement density. Price adjustments for each lot are calculated by the central laboratory the percentage of material passing 75:m based on three pay items: asphalt content, (No. 200) sieve, and the roadway density.

Table 1. Summary Statistics for Binder Mixes

Test Parameter	JMF	NB Lanes		SB Lanes		All	
		n = 271		n = 276		n = 547	
		Mean	Std. Dev.	Mean	Std. Dev.	Mean	Std. Dev.
Asphalt Content (%)	4.8	4.70	0.429	4.66	0.416	4.68	0.422
Density (pcf)	N/A	153.6	1.69	153.5	1.96	153.6	1.83
1-1/2 inch (%)	100	99.9	0.77	100.0	0.00	100.0	0.54
1 inch (%)	92	92.2	6.74	91.9	5.16	92.0	5.99
1/2 inch (%)	56	63.0	8.32	62.2	7.78	62.6	8.05
No. 4 (%)	39	40.4	5.19	42.7	5.81	41.5	5.63
No. 8 (%)	30	30.8	3.77	32.3	4.07	31.6	4.00
No. 16 (%)	19	22.1	2.70	22.2	2.81	22.2	2.75
No. 30 (%)	12	16.3	2.27	15.7	2.16	16.0	2.23
No. 50 (%)	8	11.2	1.67	10.5	1.69	10.8	1.71
No. 100 (%)	6	7.59	0.984	7.42	1.094	7.51	1.044
No. 200 (%)	4.8	5.34	0.693	5.37	0.807	5.36	0.752

Table 2. Summary Statistics for Wearing Mixes

Test Parameter	JMF	NB Lanes		SB Lanes		All	
		n = 67		n = 80		n = 147	
		Mean	Std. Dev.	Mean	Std. Dev.	Mean	Std. Dev.
Asphalt Content (%)	6.6	6.37	0.270	6.45	0.342	6.41	0.313
Density (pcf)	N/A	143.6	2.38	142.5	2.70	143.0	2.61
1/2 Inch (%)	100	100.0	0.00	100.0	0.00	100.0	0.00
3/8 Inch (%)	96	96.6	1.43	96.8	1.48	96.7	1.46
No. 4 (%)	72	70.8	4.35	71.8	3.36	71.3	3.86
No. 8 (%)	48	49.4	3.82	49.8	2.35	49.6	3.10
No. 16 (%)	34	35.0	2.49	34.9	1.49	34.9	2.00
No. 30 (%)	24	25.7	1.88	25.5	1.17	25.6	1.53
No. 50 (%)	16	16.4	1.83	16.6	1.36	16.5	1.59
No. 100 (%)	10	9.28	1.253	9.54	0.913	9.42	1.085
No. 200 (%)	4.5	5.54	0.779	5.57	0.654	5.56	0. 711

A total of 547 binder mix samples (271 in NB lanes and 276 147 wearing mix samples (67 in NB lanes and 80 in SB lanes) were in SB lanes) and obtained behind the paver and tested by the central laboratory.

A substantial amount of segregation was observed in the compacted binder course mix of this project apparently due to mix handling and placing operations. Obviously, the mix gradation of sublet samples obtained behind the paver varied considerably and it affected the extracted asphalt content. Since a large number of binder mix samples were obtained at random locations behind the paver on this project and were analyzed for mix composition (asphalt content and gradation), a unique opportunity was available for evaluating the effect of aggregate gradation on the measured asphalt contents. Material production variability was considered to be minimal on this project because an automated HMA facility was used, and the mix samples obtained at the facility were reasonably uniform in composition. The testing variability is also considered to be minimal because all extraction testing was done in the DOT central laboratory by essentially the same testing crew. ASTM D2172 (Method D) was used for extracting the asphalt cement from HMA mix samples.

It is possible to conduct a similar study in a laboratory. A mix can be prepared with a known asphalt content, intentionally segregated, and then extracted. This would eliminate the inherent material variation. However, it is not possible to simulate the segregation which occurs in the field. Also, it is not practical to test a very large number of samples as was done in this study.

TEST RESULTS

Due to space restrictions it is not possible to include the mix composition test data for 547 binder mix samples and 147 wearing mix samples in this paper. However, Tables 1 and 2 give the summary statistics for binder mixes and wearing mixes, respectively. Figures 1, 2, 3 and 4 give the control charts of the test data for asphalt content, the percent passing the 12.5mm (1/2 inch), 4.75mm (No. 4), and 2.36mm (No. 8) sieves for 271 binder mix samples obtained from the NB lanes of the paving project. The control charts of the test data from the SB lanes are similar to those of the NB lanes and, therefore, are not included due to space limitations in the paper.

ANALYSIS OF TEST RESULTS

The purpose of this study was to determine the effect of a change in gradation on the corresponding measured asphalt content. If a strong correlation exists between gradation and asphalt content, then a part of the deviation from the JMF in the measured asphalt content could be explained by the measured deviation in gradation.

As mentioned earlier, the summary statistics of mean and standard deviation for the quality assurance data is shown in Table 1 for the binder mixes and Table 2 for the wearing mixes. For the binder mixes, the standard deviation is over 5 percent for percent passing the 25.4mm (1 inch), 12.5mm (1/2 inch) and 4.75mm (No. 4) sieves, and 0.42 percent for asphalt content.

Table 2 shows lower standard deviations for the wearing mixes for most sieve sizes, and none of the sieve sizes had a standard deviation over 3.9 percent. The standard deviation for asphalt content was 0.31 YO for the wearing mixes. However, a review of the control charts showed the standard deviation for asphalt content might be artificially high due to an apparent change in the JMF asphalt content by the contractor which did not appear in the test records.

Control charts of the test data for asphalt content and the percent passing the 12.5mm (1/2 inch), 4.75mm (No. 4), and 2.36mm (No. 8) sieves for the binder mixes (NB lanes) are shown in Figures 1-4. The permissible tolerance limits for these four test parameters were ±0.5, ±8, and ±6 percent, respectively. Tables 3 and 4 show the frequency that the above test parameters were within and outside the specification tolerance limits for the binder and wearing mixes, respectively. For the binder mix, asphalt content was outside the specification limits 23.4 percent of the time and the percent passing the 12.5mm (1/2 inch), 4.75mm (No. 4), and 2.36mm (No. 8) sieves 28.9, 20.3, and 17.5 percent of the time, respectively. From the control charts and the data

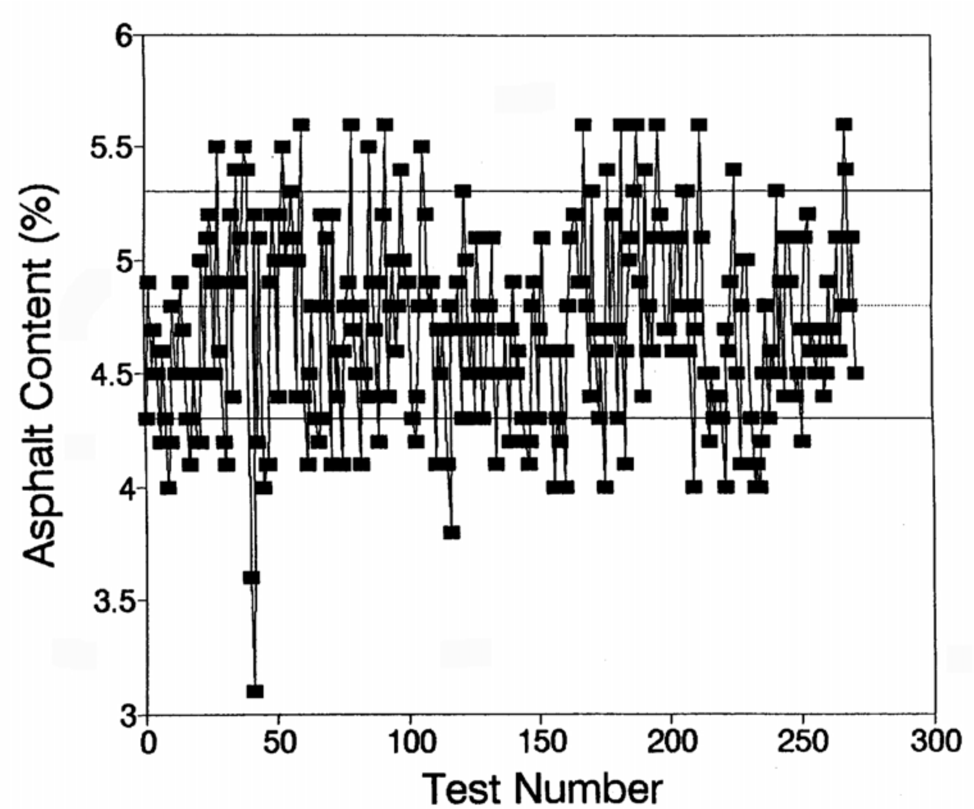

Figure 1. Control Chart for Asphalt Content in Binder Mixes (NB Lanes)

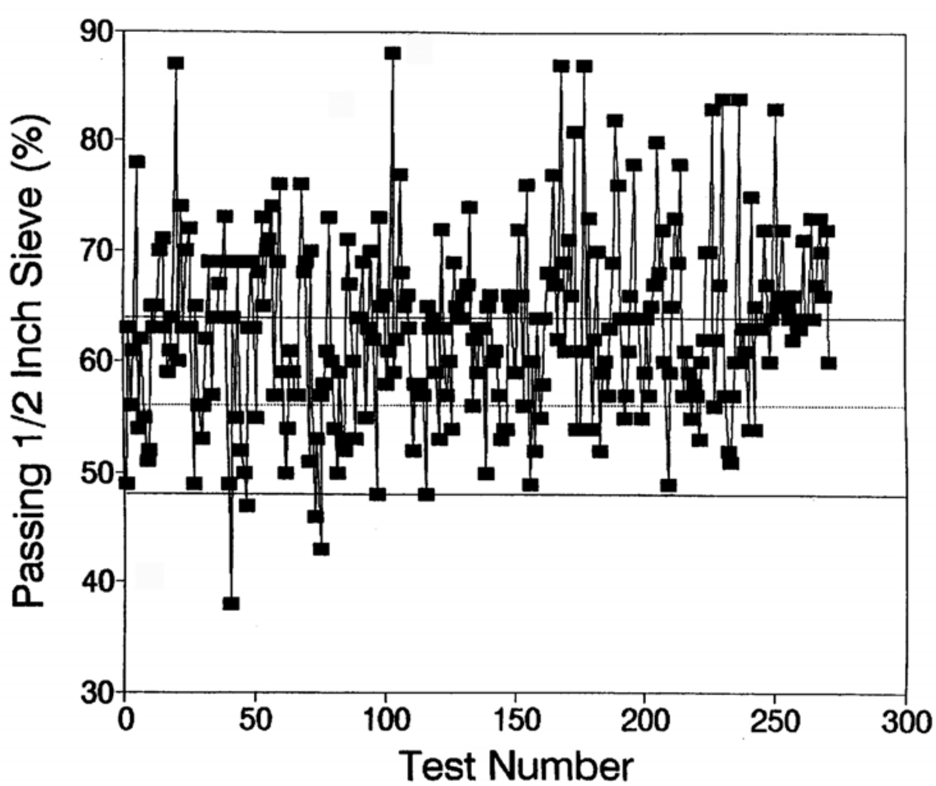

Figure 2. Control Chart for Passing 1/2 Inch Sieve in Binder Mixes (NB Lanes)

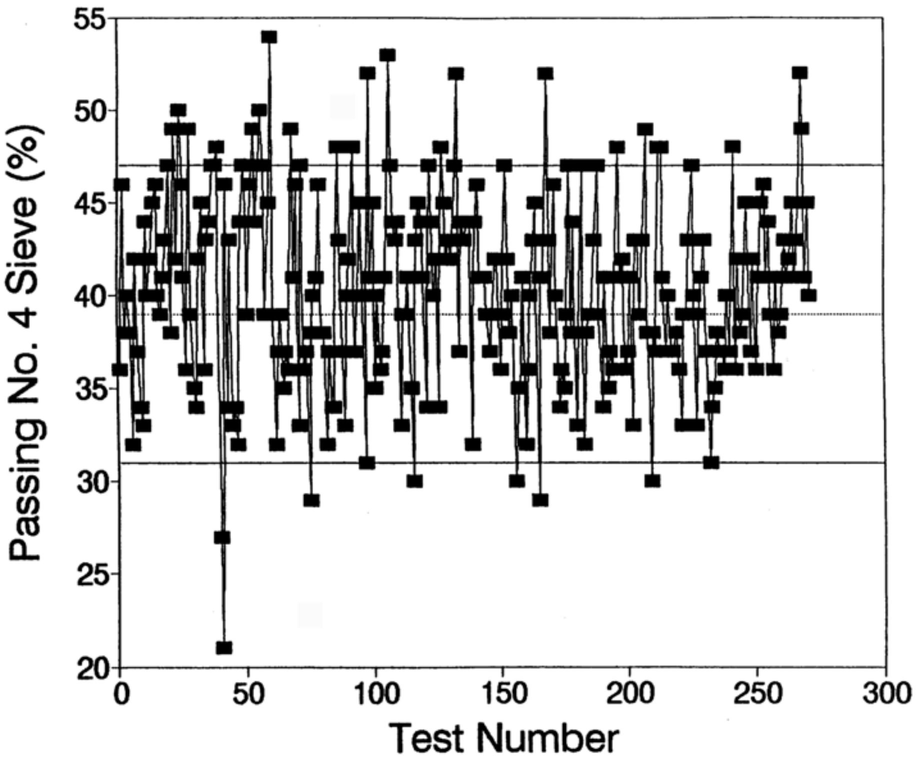

Figure 3. Control Chart for Passing No. 4 Sieve in Binder Mixes (NB Lanes)

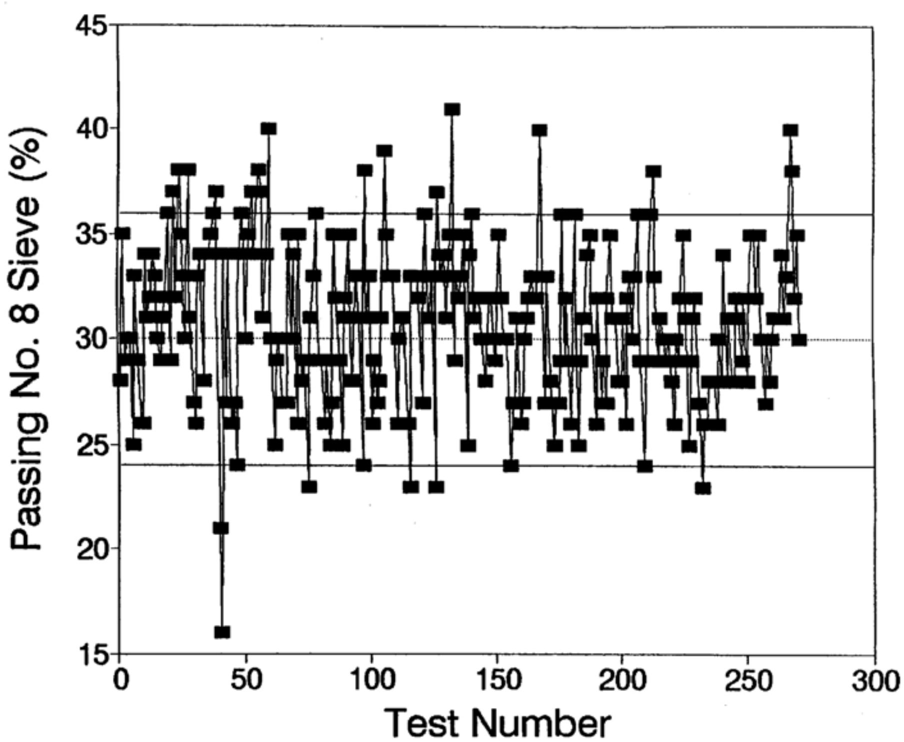

Figure 4. Control Chart for Passing No. 8 Sieve in Binder Mixes (NB Lanes)

in Table 3, it is obvious that the binder mix sampled from the roadway was not uniform. Review of the test data and visual observations showed segregation of the mix to be a major problem on both the NB and SB lanes.

Table 3. Frequency Distribution of Test Data for Binder Mixes

		NB Lanes	SB Lanes	All
Asphalt Content	In Spec.	74.2	79.0	76.6
	Out - Low	15.9	16.7	16.3
	Out - High	9.9	4.3	7.1
Percent Passing 1/2 Inch Sieve	In Spec.	67.5	74.6	71.1
	Out - Low	9.2	9.8	9.5
	Out - High	23.3	15.6	19.4
Percent Passing No. 4 Sieve	In Spec.	84.9	74.6	79.7
	Out - Low	1.5	1.5	1.5
	Out - High	13.6	23.9	18.8
Percent Passing No. 8 Sieve	In Spec.	87.8	77.2	82.5
	Out - Low	2.2	1.8	2.0
	Out - High	10.0	21.0	15.5

Table 4. Frequency Distribution of Test Data for Wearing Mixes

		NB Lanes	SB Lanes	All
Asphalt Content	In Spec.	76.1	80.0	78.2
	Out - Low	23.9	12.5	17.7
	Out - High	0.00	7.5	4. 1
Percent Passing No. 4 Sieve	In Spec.	95.5	100.0	97.9
	Out - Low	3.0	0.0	1.4
	Out - High	1.5	0.0	0.7
Percent Passing No. 8 Sieve	In Spec.	89.5	98.8	94.5
	Out - Low	1.5	0.0	0.7
	Out - High	9.0	1.2	4.8

Table 4 shows the frequency that the wearing mix test parameters of asphalt content and the percent passing the 4.75mm (No. 4) and 2.36mm (No. 8) sieves were within specification tolerance limits. The permissible tolerance limits for these three test parameters were ±0.4, ±8, and ±6 percent, respectively. Asphalt content was outside the specification limits 21.8 percent of the time, and the percent passing the 4.75mm (No. 4) and 2.36mm (No. 8) sieves 2.1 and 5.5 percent of the time, respectively. Review of the control charts and test data showed that the gradation of the mix was within project limits 95 percent of the time. Some of the scatter in asphalt content occurred when the contractor lowered the asphalt content on the NB lanes from 6.6 percent to approximately 6.2 percent after 35 tests. However, the available test data did not show a corresponding change in the JMF asphalt content. If the JMF had been changed to 6.2 percent, as the data indicates, and the applicable tolerance of 0.4 percent applied, the percent of the asphalt content tests within specification limits would change from 76.1 percent to 97.0 percent for the NB lanes and from 78.2 percent to 87.8 percent for all of the data.

Correlation analysis was performed to determine if the mat density or the percentages passing various sieve sizes correlate with asphalt content. Table 5 shows the results of the correlation analysis for the binder mixes, by lane, and with all of the data. The results show all of the parameters except unit weight (density of the core samples) and percent passing the 38.1 mm (1 1/2 inch) sieve have a high probability of a true correlation (alpha = 0.0001) with asphalt content. The best correlations with asphalt content for the binder mixes were with the percent passing the 4.75mm (No. 4) and 2.36mm (No. 8) sieves.

Table 5. Summary of Correlation Coefficients (R) with Asphalt Content for Binder Mixes

Parameter	NB Lanes n = 271		SB Lanes n = 276		All n = 547	
	R	Alpha*	R	Alpha*	R	Alpha*
Density	0.121	0.0474	-0.033	0.589	0.040	0.3546
1 1/2 Inch	0.056	0.3577	N/A	N/A	N/A	N/A
1 Inch	0.413	0.0001	0.517	0.0001	0.455	0.0001
1/2 Inch	0.649	0.0001	0.790	0.0001	0.716	0.0001
No. 4	0.822	0.0001	0.842	0.0001	0.800	0.0001
No. 8	0.819	0.0001	0.825	0.0001	0.795	0.0001
No. 16	0.738	0.0001	0.682	0.0001	0.707	0.0001
No. 30	0.635	0.0001	0.556	0.0001	0.597	0.0001
No. 50	0.586	0.0001	0.457	0.0001	0.521	0.0001
No. 100	0.640	0.0001	0.474	0.0001	0.554	0.0001
No. 200	0.611	0.0001	0.476	0.0001	0.535	0.0001

*1-Alpha = Probability correlation coefficient (R) not equal to 0.

The results of the correlation analysis for the wearing mixes are shown in Table 6. The analysis shows the highest probability of a true correlation (alpha = 0.0001) with asphalt content for the percent passing the 300:m (No. 50), 150:m (No. 100) and 75:m (No. 200) sieves. However, the correlation coefficients (R^2) are not only too low to be useful, they indicate an unexpected trend, that is, the asphalt content decreases with increase in the material passing these sieves.

To further investigate the relationship between asphalt content and gradation, regression analysis was performed. The purpose of this study is to determine if asphalt content could be predicted from measured gradation; therefore, asphalt content was selected as the dependent variable and gradation the independent variable, Table 7 is a summary of the best coefficients of determination (R^2), by lane and by mix type, for the binder and wearing mixes.

Table 6. Summary of Correlation Coefficients (R) with Asphalt Content for Wearing Mixes

Parameter	NB Lanes		SB Lanes		ALL	
	n = 67		n = 80		n = 147	
	R	Alpha*	R	Alpha*	R	Alpha*
Density	-0.022	0.8577	-0.003	0.9807	-0.038	0.6489
1/2 Inch	N/A	N/A	N/A	N/A	N/A	N/A
3/8 Inch	0.443	0.0002	0.114	0.3135	0.247	0.0025
No. 4	-0.106	0.3942	0.073	0.5174	0.009	0.9144
No. 8	-0.165	0.1824	0.124	0.2716	-0.014	0.8653
No. 16	-0.113	0.3637	0.242	0.0307	0.050	0.5495
No. 30	-0.264	0.0308	0.078	0.4940	-0.101	0.2229
No. 50	-0.418	0.0004	-0.330	0.0028	-0.345	0.0001
No. 100	-0.326	0.0071	-0.490	0.0001	-0.37 5	0.0001
No. 200	-0.257	0.0356	-0.522	0.0001	391	0.0001

* 1-Alpha = Probability correlation coefficient (R) not equal to 0.

The data in Table 7 indicates that no correlation exists between asphalt content and the percent passing the 4.75mm (No. 4) and 2.36mm (No. 8) sieves for the wearing mix. There is very little spread in the gradation data, and no segregation was observed in the field. Therefore, all of the scatter appears to be due to the normal variation in the material, sampling and testing operations.

Table 7. Summary of Coefficients of Determination (R 2) with Asphalt Content for Id2 Mixes

Number of Observations	N13 Lanes	SB Lanes	All
	n = 271	n=276	n = 547
	R 2	R 2	R 2
Independent Variable	ID2 Binder Mixes		
1/2 Inch Sieve	0.422	0.625	0.515
No. 4 Sieve	0.676	0.708	0.640
No. 8 Sieve	0.671	0.680	0.632
1/2 Inch & No. 4 Sieves	0.686	0.722	0.669
1/2 Inch & No. 8 Sieves	0.685	0.729	0.676
	ID2 Wearing Mixes		
No. 4 Sieve	0.011	0.005	0.000
No. 8 Sieve	0.027	0.016	0.000

Figures 5 and 6 show the relationship between asphalt content and the percent passing the 4.75mm (No. 4) and 2.36mm (No. 8) sieves for the binder mix in both lanes, respectively. The results show that there is a relationship between change in gradation and measured asphalt content. The relationships show that as the mix becomes finer for the given sieve size, the asphalt content increases. The relationships have the following form:

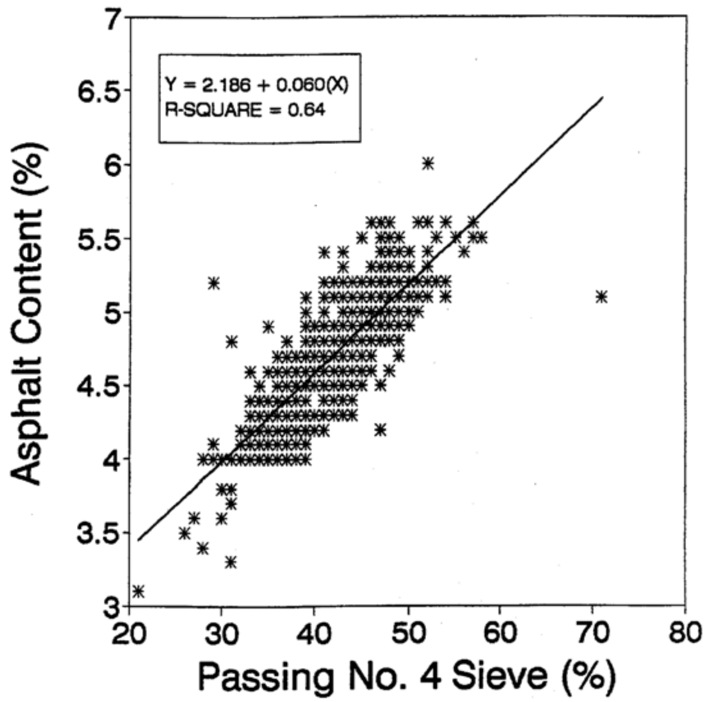

Figure 5. Percentage Passing No. 4 Sieve vs. Asphalt Content (Binder Mixes from Both Lanes)

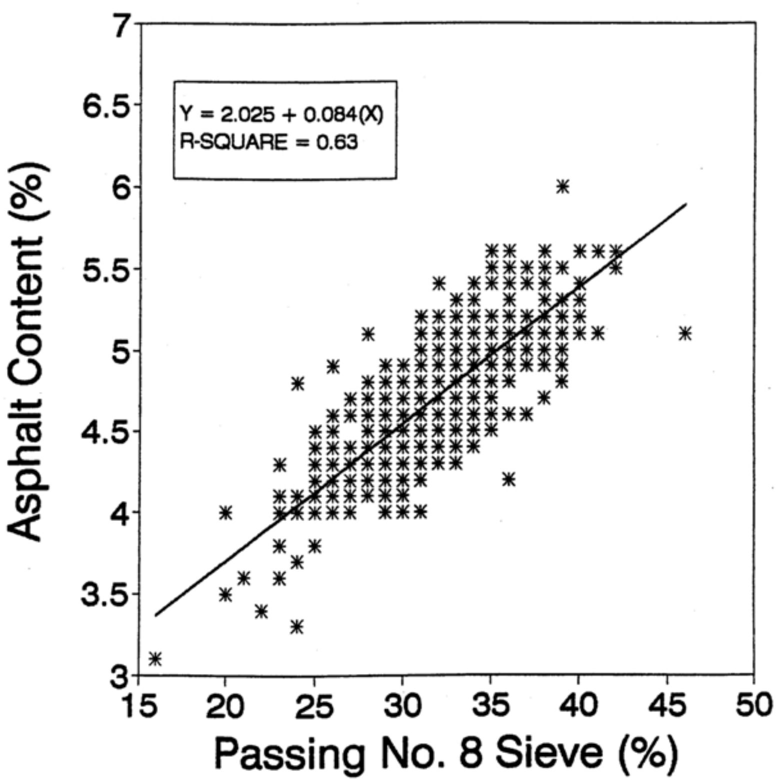

Figure 6. Percentage Passing No. 8 Sieve vs. Asphalt Content (Binder Mixes from Both Lanes)

$$AC = 2.186 + 0.060\ (P4) \qquad (1)$$
R-square = 0.64

$$AC = 2.025 + 0.084\ (P8) \qquad (2)$$
R-square = 0.63

where,
AC = Asphalt content
P4 = Percent passing the 4.75mm (No. 4) sieve
P8 = Percent passing the 2.36mm (No. 8) sieve

Equations 1 and 2 indicate that the measured asphalt contents of the binder course mix in this study increase by 0.06 and 0.08 percent (based on slopes of the regression lines) with each one percent increase in the material passing 4.75mm (No. 4) and 2.36mm (No. 8) sieves, respectively, from the JMF. Conversely, there will be a similar decrease in the measured asphalt contents if the sampled mix is coarser than the JMF. These so-called "correction factors" can be used to correct the measured asphalt content for each one percent deviation from the JMF. Some researchers (*1*, *2*, and *3*) have developed the following "correction factors" for binder course mixes (maximum aggregate size greater than 25.4mm or 1 inch) based on the material passing 2.36mm (No. 8) sieve after analyzing limited field data.

	Correction Factor, %
Customary in UK for rolled-asphalt mix prior to 1970 (*1*)	0.08
Goodsall and Mathews (*1*)	0.14
Warden (*2*)	0.16
Brown et al (*3*)	0.10
Kandhal and Cross (This paper)	0.08

The "correction factor" is expected to be generally dependent on the fine aggregate gradation, the particle shape and surface texture of the aggregates, and the actual asphalt content of the binder course mix.

Further analysis was performed to determine if a multi-variable model would give a statistically stronger model. The best multi-variable model was found by including the 12.5mm (1/2 inch) sieve with either the 4.75mm (No. 4) or 2.36mm (No. 8) sieve. The relationship between asphalt content and the percent passing the 12.5mm (1/2 inch) sieve is shown in Figure 7. The relationship has an R^2 of 0.52. By combining the 12.5mm (1/2 inch) sieve with the 4.75mm (No. 4) sieve the model has an R^2 of 0.67. The relationship has the following form:

$$AC = 1.947 + 0.014\ (P\ 1/2) + 0.045\ (P4) \qquad (3)$$
R-square = 0.67

Where,
AC = Asphalt content
P 1/2 = Percent passing 12.5mm (1/2 inch) sieve
P4 = Percent passing 4.75mm (No. 4) sieve

A slightly stronger model was found utilizing the 12.5mm (1/2 inch) and 2.36mm (No. 8) sieves. The relationship is shown in Figure 8 and has the following form:

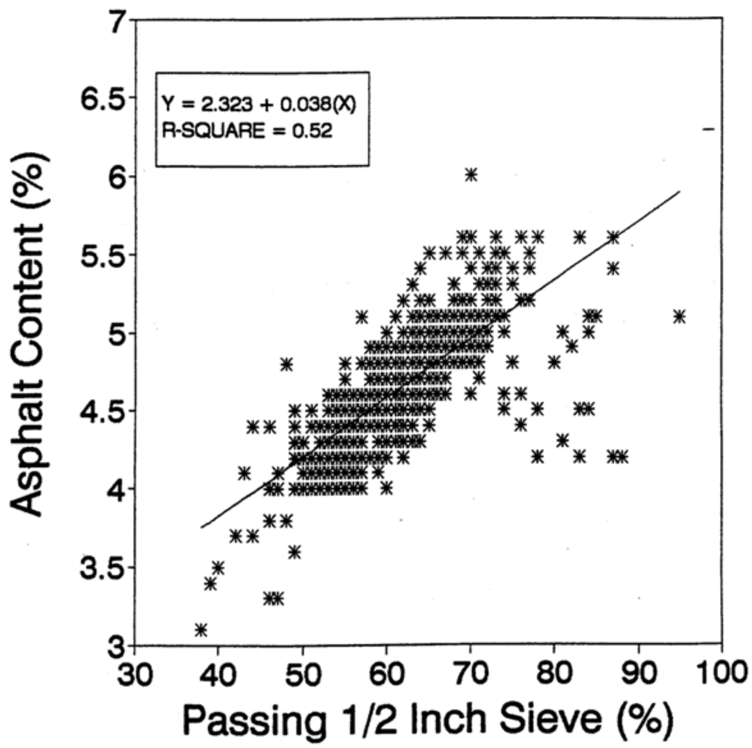

Figure 7. Percentage Passing 1/2 Inch Sieve vs. Asphalt Content (Binder Mixes from Both Lanes)

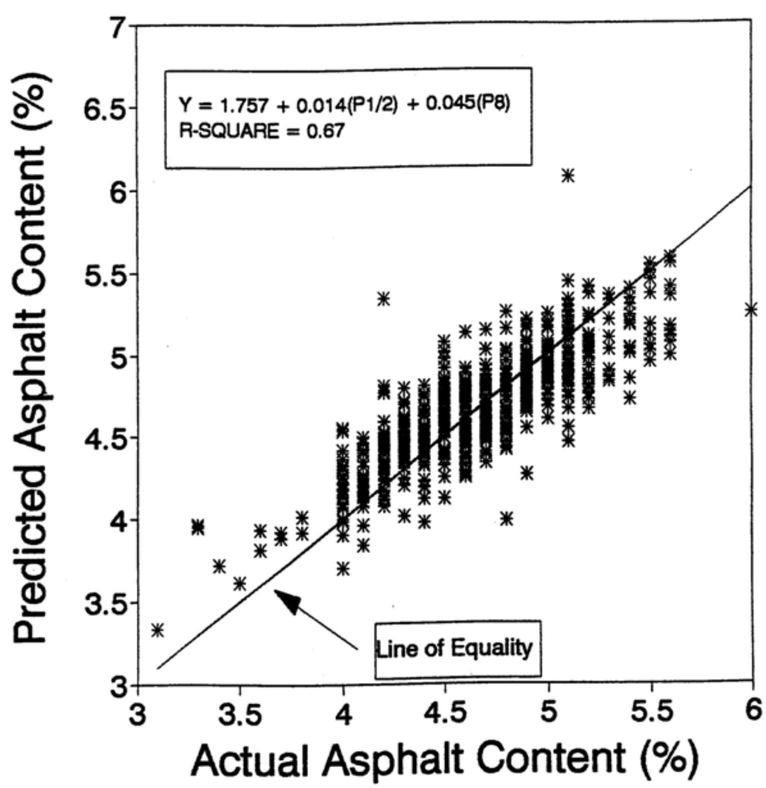

Figure 8. Actual vs. Predicted Asphalt Content (Binder Mixes from Both Lanes)

$$AC = 1.757 + 0.016\,(P\,1/2) + 0.061\,(P8) \qquad (4)$$
$$R\text{-square} = 0.68$$

where,

AC = Asphalt content
P 1/2 = Percent passing 12.5mm (1/2 inch) sieve
P8 = Percent passing 2.36mm (No. 8) sieve

The data shown in Figures 6-8 show that the measured asphalt content is affected by a change in gradation. A change in gradation will cause a corresponding change in the measured asphalt content. By utilizing either of the above four models, the measured asphalt content can be adjusted for the amount caused by the change in gradation. The adjusted asphalt content can then be checked against the tolerance limits for the JMF asphalt content to determine if the variation in asphalt content is due to the change in gradation, segregation, or a true change in the asphalt content.

To check the models developed, the measured asphalt contents were adjusted for the measured change in gradation using equations 1, 2 and 4. The adjusted asphalt content (AAC) is determined by adding the difference between the measured asphalt content (MAC) and the predicted asphalt content (PAC), to the JMF. The adjusted asphalt content is then checked against the upper and lower tolerance limits of the JMF asphalt content.

$$AAC = JMFAC + (MAC - PAC) \qquad (5)$$

where,

AAC = Asphalt content adjusted for gradation
JMFAC = Job mix formula asphalt content
MAC = Measured asphalt content
PAC = Predicted asphalt content from Eq. 1, 2, 3 or 4

Figure 9 shows the control charts for the asphalt content adjusted utilizing equation 5 for binder mix samples from NB lanes. Table 8 shows the frequency that the adjusted asphalt content, adjusted utilizing equations 1, 2 and 4, are within specification limits. The results show 95 percent of the adjusted asphalt contents within specification limits regardless of the equations utilized. The adjusted asphalt contents for the binder mix show a compliance percentage very similar to that obtained for the wearing mixes where segregation was not a problem.

Table 8. Frequency Distribution of Adjusted Asphalt Content for Binder Mixes

Asphalt Content		NB Lanes	SB Lanes	All
Adjusted on No. 4 Sieve (Eq. 1)	In Spec.	93.7	96.7	95.2
	Out - Low	0.4	0.8	0.5
	Out - High	5.9	2.5	4.2
Adjusted on No. 8 Sieve (Eq. 2)	In Spec.	94.1	96.0	95.1
	Out - Low	0.4	2.9	1.6
	Out - High	5.5	1.1	3.3
Adjusted on 1/2"& No. 8 Sieve (Eq. 4)	In Spec.	94.8	96.4	95.6
	Out - Low	1.5	0.7	1.1
	Out - High	3.7	2.9	3.3

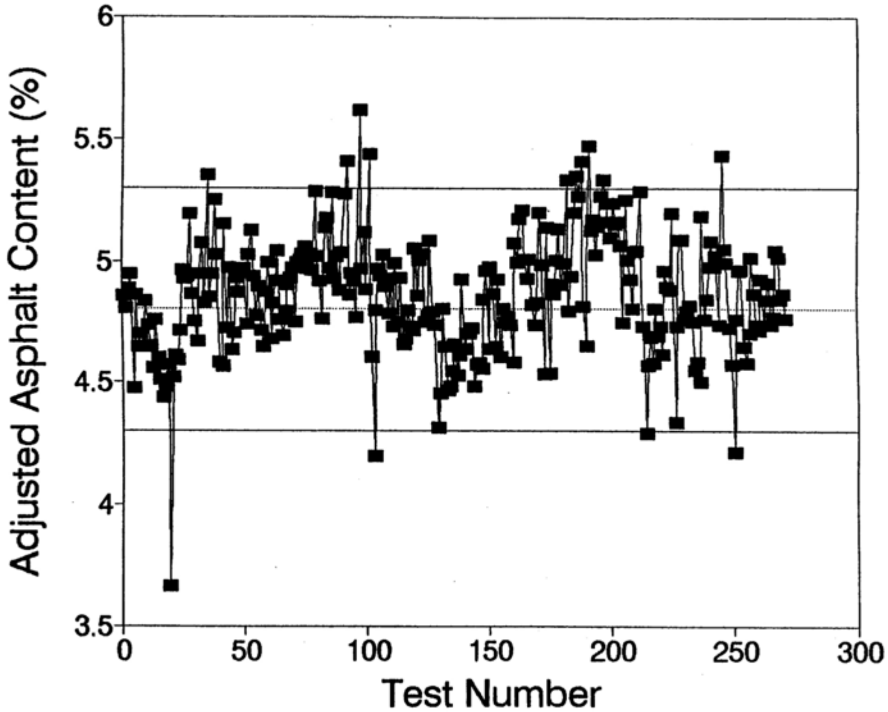

Figure 9. Control Chart for Asphalt Content Adjusted for 1/2 Inch and No. 8 Sieves (Binder Mixes from NB Lanes)

CONCLUSIONS AND RECOMMENDATIONS

Based on the data obtained in this study the following conclusions are warranted.

1. In segregated HMA pavements, some of the deviation in asphalt content from the job mix formula (JMF) is controlled by the change in gradation of the mix from the JMF.
2. When segregated binder course mixes were sampled behind the paver, the percent passing the 4.75mm (No. 4) and 2.36mm (No. 8) sieves correlated with measured asphalt content.
3. For segregated binder course mixes, the asphalt content can be adjusted to account for the change in gradation from the JMF as measured on the 12.5mm (1/2 inch) and either the 4.75mm (No. 4) or 2.36mm (No. 8) sieves as shown in equations 3 and 4. However, these equations are valid for the aggregates and the JMF used in this study. Care should be taken in applying these formulas to other mixes.
4. Since no significant segregation occurred during the laydown of the wearing course mix, gradation could not be related to the measured asphalt content.

DISCLAIMER

The opinions, findings, and conclusions expressed here are those of the authors and not necessarily those of the National Center for Asphalt Technology or Auburn University or the University of Kansas.

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