STATE OF FLORIDA

Development and Refinement of the Florida Department of Transportation's Percent Within Limits Hot Mix Asphalt Specification

Research Report
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ABSTRACT

In July 2002, the Florida Department of Transportation (FDOT) implemented a statistically based, percent within limits (PWL) specification for the acceptance and payment of hot mix asphalt. The Specification also addressed small quantities as well as single test pass/fail criteria. The same year FDOT also adopted a Contractor Quality Control (CQC) system where acceptance was based on the contractor's quality control data. The PWL specification criteria were developed based on data collected from FDOT construction projects built under the previous Quality Assurance (QA) System, where acceptance and payment were based on tests conducted by FDOT personnel.

In 2004, FDOT conducted a study to assess the PWL specifications after two years of use. The study was conducted to compare the variances generated under the old QA system to variances generated under the new CQC system. Data was collected from 79 recently completed CQC projects and analyzed. The analysis examined variances of various mixture characteristics, including roadway density, percent air voids, asphalt binder content, percent passing the No. 8 (2.36 mm) sieve, and percent passing the No. 200 (0.075 mm) sieve. The analysis also examined individual mixture characteristic pay factors and composite pay factors generated under the CQC System.

FDOT concluded that, in general, the variances and pay factor system based on data from the old QA system reflected typical values identified under the new CQC system. Only a few of the PWL specification criteria needed slight modifications to better reflect current variances. Refinements were also made to the small quantity payment system as well as the pass/fail criteria for single test results.

INTRODUCTION

The Florida Department of Transportation, herein referred to as FDOT, decided in 2001 to modify its current procedure for acceptance and payment of hot mix asphalt. Contractors' test results would be used for acceptance and a statistically based percent within limits (PWL) specification would be used to determine payment. An extensive data analysis was conducted to determine the variability of the asphalt properties used in the payment determination, and in July 2002, the new system was implemented. FDOT conducted a second analysis in 2004 to examine the effectiveness of the new system. This paper will present a brief background of the original analysis conducted in 2001 and will explain in detail the results of the second analysis and modifications made to FDOT specifications.

SUMMARY OF 2001 ANALYSIS

Data for the following hot mix asphalt properties was analyzed: 1) roadway density, 2) percent air voids, 3) asphalt binder content, 4) percent passing the No. 8 sieve, and 5) percent passing the No. 200 sieve. A total of 4377 cores were used in the analysis of roadway density and 1920 test results were used in the analysis for each of the other four properties. Data from a wide range of contractors and mixture types was included. Median lot standard deviations were calculated for each material property. A typical lot is defined as four 1000-ton sublots and contains one test result per sublot for percent air voids, asphalt binder content, percent passing the No. 8 sieve, and percent passing the No. 200 sieve. For roadway density, five cores are obtained per sublot and are averaged to obtain one density value per sublot.

FDOT used the method presented in the AASHTO Quality Assurance Guide Specification (1) and NCHRP Report 447 (2) to develop the specification limits for each asphalt material property. In this method, a contractor can receive 100 percent payment if 90 percent of the estimated population (as determined by the contractor's test results) is within the upper and lower specification test limits. The median standard deviations are multiplied by 1.645 to obtain the specification limits for each material property. 1.645 is the z-value multiplier representing the number of standard deviations from the mean that would encompass 90 percent of the test values for each material property. The median standard deviations, calculated specification limits, implemented specification limits and target values are shown in Table 1 for each material property. Implemented specification limits were based on the calculated specification limits and were adjusted based on engineering judgment.

Table 1 – Standard Deviations, Specification Limits and Target Values from 2001 Analysis

Asphalt Material Property	Median Standard Deviation	Calculated Specification Limits (Std. Dev. x 1.645)	Implemented Specificaion Limits	Target Value
Roadway Density, % Gmm (coarse mixtures)	0.51	0.84	+/- 1.30	94.50
Roadway Density, % Gmm (fine mixtures)	0.60	0.99	+2.00, -1.00	93.00
% Air Voids	0.75	1.23	+/- 1.40	4.00
Asphalt Binder Content	0.21	0.35	+/- 0.40	Mix Design
% Passing No. 8	1.88	3.09	+/- 3.10	Mix Design
% Passing No. 200	0.40	0.66	+/- 1.00	Mix Design

FDOT also used the method presented in the AASHTO Quality Assurance Guide Specification (1) to calculate the pay factor amount used to determine the contractor's payment. The following equation is used to determine the pay factor:

$$\text{Pay factor (\%)} = 55 + 0.5 \times \text{PWL}$$

In the FDOT acceptance and payment system, a pay factor is calculated for each material property and then a composite pay factor is calculated by multiplying each individual pay factor by a weighting factor as shown in Table 2.

Table 2 – Material Property Weighting Factors

Material Property	Weight (%)
Roadway Density	35
Percent Air Voids	25
Asphalt Binder Content	25
Percent Passing No. 8 Sieve	5
Percent Passing No. 200 Sieve	10
Total	100

The PWL system is not designed to work in situations with one or two sublots, therefore FDOT developed a small quantity pay table. Payment is based on the absolute value deviation of a single test result or absolute value average deviation of two test results from the target value. Larger deviations from the target result in lower pay factors. The values contained within the small quantity pay table are partially based on the findings from the material property analysis mentioned previously and partially from engineering judgment. The small quantity pay table developed in 2001 is shown in Table 3.

FDOT also developed an acceptable range for each material property for which individual test results are expected to meet. FDOT uses this range (termed the master production range) to identify and limit any potentially substandard material and/or asphalt plant production problems. Similar to the small quantity pay table, the master production

Table 3 – Small Quantity Pay Table from 2001 Analysis

Material Property	Pay Factor	1-Test Deviation	2-Test Average Deviation
Percent Asphalt Binder Content	1.00	0.00-0.45	0.00-0.32
	0.90	0.46-0.55	0.33-0.39
	0.80	>0.55	>0.39
Percent Passing No. 8 Sieve	1.00	0.00-4.50	0.00-3.18
	0.90	4.51-5.50	3.19-3.89
	0.80	>5.50	>3.89
Percent Passing No. 200 Sieve	1.00	0.00-1.10	0.00-0.78
	0.90	1.11-1.50	0.79-1.06
	0.80	>1.50	>1.06
Percent Air Voids	1.00	0.00-1.10	0.00-0.78
	0.90	1.11-1.50	0.79-1.06
	0.80	>1.50	>1.06
Roadway Density (Coarse Graded Mixtures) Note (1)	1.00	≥ 93.50	≥ 93.50
	0.95	93.00-93.49	93.00-93.49
	0.90	Note (2)	Note (2)
Roadway Density (Fine Graded Mixtures) Note (1)	1.00	≥ 92.00	≥ 92.00
	0.95	91.00-91.99	91.00-91.99
	0.90	90.00-90.99	90.00-90.99
	0.80	< 90.00	< 90.00

Notes:
(1) Each density test result is the average of five cores.
(2) In the event that the density of a LOT is less than 93.00% of G_{mm}, FDOT will assess the pavement's permeability in accordance with FM 5-565. If the coefficient of permeability is greater than or equal to 125 x 10^{-5} cm/s, the Engineer may require removal and replacement at no cost or may accept the payment at 90% pay. The contractor may remove and replace at no cost to the FDOT at any time.

range was developed based on the findings from the material property analysis mentioned previously, as well as engineering judgment. The master production range tolerance for each material property was established as the same value as the "1-test deviation" value for the lowest pay factor for each material property contained in the small quantity pay table. The master production range is shown in Table 4.

Table 4 – Master Production Range from 2001 Analysis

Asphalt Material Property	Tolerance from Mix Design (for one test)
Roadway Density (1) - Coarse Mixtures	93.00 %G_{mm} minimum
Roadway Density - Fine Mixtures	N/A
Percent Air Voids	4.00 +/- 1.50
Percent Asphalt Binder	Target +/- 0.55
Percent Passing No. 8 Sieve	Target +/- 5.50
Percent Passing No. 200 Sieve	Target +/- 1.50
(1) Roadway Density is the average of five cores.	

The aforementioned discussion of PWL development, the small quantity pay table and the master production range is with respect to dense graded hot-mix asphalt. FDOT also performed the same analysis and development procedure for open graded friction course mixtures. For the sake of brevity, this information will not be included in this paper. For further information, the development of FDOT's procedures for acceptance and payment of dense and open graded hot mix asphalt is documented in two reports (3, 4).

2004 ANALYSIS PLAN

Approximately two years after the implementation of the new PWL specification, FDOT conducted a follow-up study to compare the variability of the material properties resulting from the old QA system to the variability resulting from the new PWL system. The purpose of the study was to assess the functionality and performance of the new system and make modifications as necessary.

The analysis plan consisted of compiling and analyzing test result and pay factor data from projects constructed under the new PWL specification. The data included all mix design types utilized in Florida, large and small tonnage projects and included data from a wide range of asphalt contractors. Following the analysis, meetings were held with representatives of FDOT, Industry and the Federal Highway Administration to discuss the analysis results and agree upon modifications to the specifications.

2004 VARIABILITY ANALYSIS

Data was collected throughout Florida from 18 contractors and represented 79 projects, 152 mix designs, 480 lots and 1848 sublots. For each project and mix design, the within-lot variance was determined. Data from different mix designs within the same project was not intermingled. The variance between lots, commonly known as “target miss”, was also calculated. The two variance values, within-lot and target miss, were summed to result in the total lot variance for a particular mix design for a project. This procedure is discussed in AASHTO document R 9-04 (5) and FHWA publication RD-02-095 (6). This process was completed for all 152 mix designs. The median variance was then determined and was converted to a median standard deviation for each material property. The results of the analysis are shown in Table 5.

Table 5 – Median Standard Deviations from 2004 Analysis

Asphalt Material Property	Median Pooled LOT Variance (A)	Median Variance of LOT Averages (B)	Overall Median Variance (C = A + B)	Overall Median Standard Deviation (C^0.5)
Roadway Density, % Gmm (coarse mixtures)	0.521	0.189	0.711	0.843
Roadway Density, % Gmm (fine mixtures)	0.502	0.224	0.726	0.852
% Air Voids (Coarse)	0.417	0.282	0.699	0.836
% Air Voids (Fine)	0.262	0.104	0.366	0.605
AC Content	0.032	0.011	0.043	0.207
% Passing No. 8	2.896	1.032	3.929	1.982
% Passing No. 200	0.100	0.057	0.157	0.396

Subsequent to the calculation of the median standard deviation for each material property, the specification limits were then calculated by multiplying the median standard deviation by 1.645 to provide limits that would encompass 90 percent of the test values for each material property. The calculated specification limits and the limits from the previous analysis in 2001 are shown Table 6.

Table 6 – PWL Limits from 2004 and 2001 Analyses

Asphalt Material Property	Median Standard Deviation from 2004 Analysis	Calculated PWL Limits from 2004 Analysis	Calculated PWL Limits from 2001 Analysis	Implemented PWL Limits from 2001 Analysis
Roadway Density, % Gmm (coarse mixtures)	0.84	1.39	0.84	1.30
Roadway Density, % Gmm (fine mixtures)	0.85	1.40	0.99	+2.00, -1.00
% Air Voids (coarse)	0.84	1.38	1.23	1.40
% Air Voids (fine)	0.61	1.00	1.07	1.40
AC Content	0.21	0.34	0.35	0.40
% Passing No. 8	1.98	3.26	3.09	3.10
% Passing No. 200	0.40	0.65	0.66	1.00

The calculated specification limits from the 2004 analysis were in close agreement to the values calculated in the 2001 analysis, except for roadway density. However, the roadway density specification limits that were actually implemented as a result of the 2001 analysis were in agreement with the 2004 calculated specification limits.

The reasons for the discrepancy between the calculated density specification limits of the 2001 and 2004 analyses are not completely certain. In the previous QA system, roadway density testing was performed by FDOT personnel and roadway lots were defined differently from plant lots. Density was determined for one roadway core per sublot (1000 linear feet) and a lot was defined as five sublots (5000 linear feet). Furthermore, the target density value was based on a minimum value with no maximum density value specified. The variances calculated with this QA data were then mathematically manipulated to obtain variance values that would apply to the new sublot and lot definitions under the new PWL system.

Both analyses showed that air voids measured in gyratory compacted specimens at the asphalt plant were less variable for fine graded mixtures than coarse graded mixtures. Variability of roadway density was equal for fine graded and coarse graded mixtures in the 2004 analysis.

2004 PAY FACTOR ANALYSIS

Pay factor data was collected throughout Florida from 22 contractors and represented 143 projects, 237 mix designs, 778 lots and 2,480 sublots. The data was categorized by lot size, i.e. three or more sublots representing payment with the PWL system and two or less sublots representing payment with the small quantity pay table. Data was further categorized by gradation type, coarse or fine, determined by the primary control sieve point.

PWL Pay Factor Analysis

The average pay factor for each material property and the composite pay factor are shown in Table 7.

Table 7 – PWL (3 or 4 sublots per lot) Pay Factors

Mixture Type	Average Pay Factor					
	-8	-200	AC	Air Voids	Density	Composite
All Mixtures	0.97	1.01	1.01	1.02	0.98	1.00
Coarse Mixtures	0.99	1.02	1.01	1.01	0.99	1.00
Fine Mixtures	0.96	1.00	1.01	1.03	0.97	1.00

When establishing the original specification limits, FDOT's goal was to average a 1.00 pay factor for each quality characteristic and composite pay factor. The intent was to pay 100 % for hot mix asphalt of equal quality to that hot mix asphalt produced prior to the implementation of the PWL system. Results of the pay factor analysis indicate that the specification limits for the individual material properties would need a slight adjustment for each to average a 1.00 pay factor, but as a system, FDOT obtained the desirable composite pay factor of 1.00. There were slight differences in the individual pay factors for coarse and fine graded mixtures, however, the composite pay factor for both mixture types was 1.00.

Small Quantity Pay Factor Analysis

The average pay factor for each material property and the composite pay factor are shown in Table 8.

Table 8 – Small Quantity (1 or 2 sublots per lot) Pay Factors

Mixture Type	Average Pay Factor					
	-8	-200	AC	Air Voids	Density	Composite
All Mixtures	0.98	0.98	0.99	0.92	0.98	0.97
Coarse Mixtures	0.96	0.98	0.99	0.89	0.96	0.96
Fine Mixtures	0.98	0.98	0.98	0.93	0.99	0.97

Unlike the PWL specification, there was no provision for a bonus when paying for material from a lot with one or two sublots. Therefore, it was expected that the individual and composite pay factors would be less than 1.00. As with the PWL pay factors for air voids shown in Table 7, the small quantity pay factor for air voids was less for coarse graded mixtures than for fine graded mixtures.

SPECIFICATION CHANGES

After the variability and pay factor analyses were completed, several meetings were held with Industry and the FHWA. Using the previously described statistical analyses, as well as engineering judgment, changes were made to FDOT's asphalt specification.

PWL Specification

Table 9 shows a summary of the specification limits and pay factors for all of the material properties.

Table 9 – Specification Limits and Pay Factor Summary from 2004 Analysis

Asphalt Material Property	Median Standard Deviation	Calculated PWL Specification Limits (Std. Dev. x 1.645)	Current PWL Specification Limits	Avg. Pay Factor	Proposed PWL Specification Limits
Roadway Density, % Gmm (coarse mixtures)	0.84	1.39	Target = 94.5 +/- 1.30	0.99	Target = 94.5 +/- 1.30
Roadway Density, % Gmm (fine mixtures)	0.85	1.40	Target = 93.0 +2.00, -1.00	0.97	Target = 93.0 +2.00, -1.20
Roadway Density, % Gmm (fine mixtures)	Static Rolling (no previous data available)				Target = 92.0 +3.00, -1.20
% Air Voids (coarse)	0.84	1.38	+/- 1.40	1.00	+/- 1.40
% Air Voids (fine)	0.61	1.00	+/- 1.40	1.03	+/- 1.20
AC Content	0.21	0.34	+/- 0.40	1.01	+/- 0.40
% Passing No. 8	1.98	3.26	+/- 3.10	0.97	+/- 3.10
% Passing No. 200	0.40	0.65	+/- 1.00	1.01	+/- 1.00

As shown in Table 9, there is good agreement between the variability and the pay factor analyses. When the variability analysis showed that the calculated 2004 specification limits should be greater than the current specification limits derived from the 2001 analysis, the average pay factor for that property was less than 1.00. For the converse, when the variability analysis showed that the calculated 2004 specification limits should be less than the current specification limits derived from the 2001 analysis, the average pay factor for that property was greater than 1.00.

After discussions were held between FDOT, Industry and the FHWA, three changes were made to the PWL portion of the specification: 1) the lower specification limit for roadway density of fine graded mixtures was increased from 1.00 to 1.20 % Gmm, 2) a separate provision was also made for static rolling of fine graded mixtures to allow for a lower target value (92.00 vs. 93.00 % Gmm) and a higher upper specification limit (+3.00% of Gmm), and 3) air voids for coarse and fine graded mixtures were separated and the specification limit for fine graded mixtures was narrowed to +/- 1.20 % from a target of 4.00%. The specification limits for coarse graded mixtures and all of the other material properties were left unchanged. The provision for static rolling was added for those construction projects that contained vibration sensitive areas (underlying utilities, historic buildings, medical offices, etc.). The target density level was lowered by 1.00 % to account for the more difficult nature in obtaining density using static rolling as compared to vibratory rolling.

Small Quantity Pay Table

FDOT also included provisions for a bonus in the small quantity pay table with the intention to bring the statewide average pay factor to 1.00. The allowable deviations for a 1.00 pay factor from the previous small quantity pay table were simply divided in half to obtain the new deviations to achieve a pay factor of 1.05 (see Table 10).

The material property of air voids was separated for coarse and fine graded mixtures, with the allowable deviations for fine graded mixtures established at a slightly reduced level compared to those values for coarse graded mixtures. Due to the perceived importance of air voids on the performance of asphalt mixtures, two additional pay factors were established (0.70 and 0.55) for the air voids property. Other than the provision for a bonus, no changes were made to the small quantity pay table for the material properties of roadway density, asphalt binder content, percent passing the #8 sieve and percent passing the #200 sieve.

Table 10 – Small Quantity Pay Table from 2004 Analysis

Pay Factor	1-Test Deviation	2-Test Average Deviation
Asphalt Binder Content		
1.05	0.00 - 0.23	0.00 - 0.16
1.00	0.24 - 0.45	0.17 - 0.32
0.90	0.46 - 0.55	0.33 - 0.39
0.80	> 0.55	> 0.39
No. 8 [2.36 mm] Sieve		
1.05	0.00 - 2.25	0.00 - 1.59
1.00	2.26 - 4.50	1.60 - 3.18
0.90	4.51 - 5.50	3.19 - 3.89
0.80	> 5.50	> 3.89
No. 200 [75 µm] Sieve		
1.05	0.00 - 0.55	0.00 - 0.39
1.00	0.56 - 1.10	0.40 - 0.78
0.90	1.11 - 1.50	0.79 - 1.06
0.80	> 1.50	> 1.06
Air Voids (coarse)		
1.05	0.00 - 0.55	0.00 - 0.39
1.00	0.56 - 1.10	0.40 - 0.78
0.90	1.11 - 2.00	0.79 - 1.41
0.80	2.01 - 2.25	1.42 - 1.59
0.70	2.26 - 2.50	1.60 - 1.77
0.55	> 2.50	> 1.77
Air Voids (fine)		
1.05	0.00 - 0.50	0.00 - 0.35
1.00	0.51 - 1.00	0.36 - 0.71
0.90	1.01 - 1.70	0.72 - 1.20
0.80	1.71 - 2.00	1.21 - 1.41
0.70	2.01 - 2.50	1.42 - 1.77
0.55	> 2.50	> 1.77
Density (Coarse Graded Mixtures) Note (1)		
1.05	0.00 - 0.50	0.00 - 0.35
1.00	0.51 - 1.00	0.36 - 0.71
0.95	1.01 - 1.50	0.72 - 1.06
0.90	> 1.50	> 1.06
Density (Fine Graded Mixtures) Note (1)		
1.05	0.00 - 0.50	0.00 - 0.35
1.00	0.51 - 1.00	0.36 - 0.71
0.95	1.01 - 2.00	0.72 - 1.41
0.90	2.01 - 3.00	1.42 - 2.12
0.80	> 3.00	> 2.12

Notes:

(1) Each density test result is the average of five cores. The target density for coarse graded mixtures is 94.5 percent of Gmm. The target density for fine graded mixtures is 93.00 percent of Gmm (92.00 percent when compaction is limited to static mode).

Master Production Range

The median standard deviations for each material property were multiplied by three to obtain ranges that would theoretically encompass over 99 percent of the population. These values were used as a guide to evaluate the master production range limits. Table 11 shows the previous master production range values, 3x standard deviation values and the master production range values agreed upon during committee meetings.

Changes were made to the limits for air voids due to the observed variability and the excessively high rate of master production range failures that occurred while using the values implemented after the 2001 analysis. Additionally, a minimum roadway density level was added for fine graded mixtures. No other changes were made to the master production range.

Table 11 – Master Production Range Summary from 2004 Analysis

Asphalt Material Property	MPR from 2001 Analysis	Median Standard Deviation x 3	MPR from 2004 Analysis
Roadway Density, % Gmm (coarse mixtures)	93.00 minimum	2.53	93.00 minimum
Roadway Density, % Gmm (fine mixtures)	n/a	2.56	90.00 minimum
% Air Voids (coarse)	+/- 1.50	2.51	+/- 2.00
% Air Voids (fine)	+/- 1.50	1.82	+2.00, -1.70
Asphalt Binder Content	+/- 0.55	0.62	+/- 0.55
% Passing No. 8	+/- 5.50	5.95	+/- 5.50
% Passing No. 200	+/- 1.50	1.19	+/- 1.50

CONTRACTOR QUALITY CONTROL DATA COMPARED TO FDOT VERIFICATION DATA

The system implemented in 2002 was a major departure from the previous system the FDOT was using with respect to the test data used to determine payment. Under the previous system, material acceptance was based on FDOT test results. Under the new system, material acceptance is based on contractor quality control test results, provided that the test results are verified by FDOT tests. FDOT personnel perform verification testing on a random basis at a frequency of one test per lot, with a typical lot consisting of four sublots. Quality control and FDOT test results are compared and evaluated using accepted precision values.

Quality control and FDOT verification test results should be equivalent over a wide range of projects if the system is working correctly, there is no bias in equipment or testing and no data misrepresentation is occurring. Furthermore, the average difference and standard deviation of the differences can be calculated to develop 95% confidence intervals for future test result comparisons between quality control and FDOT test data. Table 12 shows the results of the aforementioned analysis. The average difference is essentially equal to zero for all of the properties.

Table 12 – Comparison of Quality Control Data and FDOT Verification Data

Material Property	Number of Comparisons	Average Difference (QC-FDOT)	Standard Deviation of Differences	95% Confidence Interval for Difference (+/-)
Gmm	462	-0.001	0.0095	0.019
Gmb (gyratory pills) average of two specimens	459	-0.001	0.0103	0.020
Gmb (roadway cores)	1398	0.0019	0.0099	0.019
% AC Content	458	-0.04	0.1789	0.35
% Air Voids	458	-0.004	0.5575	1.09
% Passing #8 Sieve	464	-0.30	2.1017	4.12
% Passing #200 Sieve	464	-0.07	0.5038	0.99
VMA	457	0.01	0.4294	0.84
Pill Height at Ndes (mm)	440	0.08	0.9978	2.0

CONCLUSIONS

1. Results of the 2004 material property variability analysis indicated that the specification limits established from the 2001 analysis were reasonable with only slight adjustments needed for roadway density and air voids, both for fine graded mixtures.
2. The 2004 pay factor analysis showed that the average composite pay factor equaled 1.0, which was the original goal of the specification. Some of the individual material property pay factors did not average 1.0, agreeing with the results of the material property variability analysis. Adjustments were made to the specification limits, with the goal that all individual pay factors will average 1.0.
3. The small quantity pay table was modified to allow for a five percent bonus and slight modifications were made to the allowable deviations for the air voids parameter.

4. The air voids parameter limits were increased for the master production range to reduce the large number of failures that occurred while using the limits from the previous specification.
5. A comparison of contractor quality control and FDOT verification data showed excellent agreement between test values.

RECOMMENDATIONS

1. The FDOT should continue to periodically examine the material property variability and pay factor distribution and make modifications to the specification as necessary.
2. Analysis and assessment of the FDOT's and contractor's risk is needed.

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