Evaluating the Impacts of Reducing the Number of Hot Mix Asphalt Plant Testing Acceptance Criteria on Mix Variability

Eric Jackson, PhD (University of CT)
James Mahoney, MS (University of CT)

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James A. Fallon, P.E.
Manager of Design Services

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16. Abstract:

The acceptance testing of Hot Mix Asphalt (HMA) conducted at the HMA production facility is an important portion of the overall acceptance process used by the Connecticut Department of Transportation (ConnDOT) for paving projects. In 2004, ConnDOT made the decision to implement a Quality Assurance (QA) approach to improve the quality of the construction of transportation facilities in the state. Until the 2009 paving season, ConnDOT had over 26 different Quality Assurance/Quality Control (QA/QC) criteria that HMA producers must meet (within limits) or face penalties, rejection of material or plant shutdown. In 2009, ConnDOT reduced the number of quality assurance metrics from 26 to 8 for the 2009 construction season. These eight metrics are: Va (Voids); VMA (Voids Mineral Agg); Gmm (Max Theoretical Gravity); Pb (Binder); and, four gradation control points (each mix has four control points that define the mix). The objective of this study was to statistically analyze HMA quality assurance data collected by ConnDOT from the 2007, 2008, 2009 and 2010 construction seasons to determine what impact the change in specifications had on the variability and overall quality of the mixes being produced. The results of this study indicate there is no overall statistically significant decrease in variability due to the 2009 specification changes. However, there is also no significant increase in variability due to the reduced testing. According to ConnDOT, these changes in specifications have eliminated costly plant shutdowns, a monetary savings to producers that will hopefully be passed down to ConnDOT in reduced pavement costs. Furthermore, the elimination of plant shutdowns will save ConnDOT and the traveling public costly project delays due to material not passing stringent quality assurance metrics, while not impacting the quality of pavement being placed.

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Standard Conversions

SI* (MODERN METRIC) CONVERSION FACTORS				
APPROXIMATE CONVERSIONS TO SI UNITS				
SYMBOL	**WHEN YOU KNOW**	**MULTIPLY BY**	**TO FIND**	**SYMBOL**
		LENGTH		
in	inches	25.4	millimeters	mm
ft	feet	0.305	meters	m
yd	yards	0.914	meters	m
mi	miles	1.61	kilometers	km
		AREA		
in^2	square inches	645.2	square millimeters	mm^2
ft^2	square feet	0.093	square meters	m^2
yd^2	square yard	0.836	square meters	m^2
ac	acres	0.405	hectares	ha
mi^2	square miles	2.59	square kilometers	km^2
		VOLUME		
fl oz	fluid ounces	29.57	milliliters	mL
gal	gallons	3.785	liters	L
ft^3	cubic feet	0.028	cubic meters	m^3
yd^3	cubic yards	0.765	cubic meters	m^3
		NOTE: volumes greater than 1000 L shall be shown in m^3		
		MASS		
oz	ounces	28.35	grams	g
lb	pounds	0.454	kilograms	kg
T	short tons (2000 lb)	0.907	megagrams (or "metric ton")	Mg (or "t")
		TEMPERATURE (exact degrees)		
°F	Fahrenheit	5 (F-32)/9 or (F-32)/1.8	Celsius	°C
		ILLUMINATION		
fc	foot-candles	10.76	lux	lx
fl	foot-Lamberts	3.426	candela/m^2	cd/m^2
		FORCE and PRESSURE or STRESS		
lbf	poundforce	4.45	newtons	N
lbf/in^2	poundforce per square inch	6.89	kilopascals	kPa
APPROXIMATE CONVERSIONS FROM SI UNITS				
SYMBOL	**WHEN YOU KNOW**	**MULTIPLY BY**	**TO FIND**	**SYMBOL**
		LENGTH		
mm	millimeters	0.039	inches	in
m	meters	3.28	feet	ft
m	meters	1.09	yards	yd
km	kilometers	0.621	miles	mi
		AREA		
mm^2	square millimeters	0.0016	square inches	in^2
m^2	square meters	10.764	square feet	ft^2
m^2	square meters	1.195	square yards	yd^2
ha	hectares	2.47	acres	ac
km^2	square kilometers	0.386	square miles	mi^2
		VOLUME		
mL	milliliters	0.034	fluid ounces	fl oz
L	liters	0.264	gallons	gal
m^3	cubic meters	35.314	cubic feet	ft^3
m^3	cubic meters	1.307	cubic yards	yd^3
		MASS		
g	grams	0.035	ounces	oz
kg	kilograms	2.202	pounds	lb
Mg (or "t")	megagrams (or "metric ton")	1.103	short tons (2000 lb)	T
		TEMPERATURE (exact degrees)		
°C	Celsius	1.8C+32	Fahrenheit	°F
		ILLUMINATION		
lx	lux	0.0929	foot-candles	fc
cd/m^2	candela/m^2	0.2919	foot-Lamberts	fl
		FORCE and PRESSURE or STRESS		
N	newtons	0.225	poundforce	lbf
kPa	kilopascals	0.145	poundforce per square inch	lbf/in^2

*SI is the symbol for the International System of Units. Appropriate rounding should be made to comply with Section 4 of ASTM E380. (Revised March 2003)

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Introduction

The acceptance testing of Hot Mix Asphalt (HMA) conducted at the HMA production facility is an important portion of the overall acceptance process used by the Connecticut Department of Transportation (ConnDOT) for paving projects. This process is documented in the Department's Quality Assurance Program for Materials (ConnDOT, 2009) that is reviewed and approved by the Federal Highway Administration (FHWA). The testing of HMA during production assures that the material leaving the production facility meets or exceeds the quality characteristics required by specification and fulfills ConnDOT's obligation to FHWA to perform Quality Assurance (QA) testing on projects using federal funds.

Ideally, all of the HMA leaving the production facility would be tested to ensure its quality. Given the vast quantities of materials produced and the limited resources to perform such testing, it is not possible to test every load of material leaving the production facility. Therefore, a statistical approach has been developed to balance the risk to both the producer and ConnDOT by testing limited quantities of material. This procedure generally requires the use of stratified random samples taken throughout the production process and is generally the overall basis for QA testing of all materials.

Some of the characteristics measured from these randomly drawn samples include: asphalt content; air voids, voids in the mineral aggregate, voids filled with asphalt; aggregate gradation, percent compaction at N initial gyrations; and, maximum theoretical specific gravity. There is a strong inter-relationship between many of these characteristics such that changes with one of them will impact others. An example of this would be changes in gradation will impact the voids in the mineral aggregate which in turn will affect the voids filled with asphalt. Because of these inter-relationships, it may not be necessary to test for all of the characteristics currently being measured.

The Federal Highway Administration (FHWA (2004)) outlines the quality control and quality assurance tests, limits and pay factors reported by the majority of states. The report for the FHWA indicates the number of tests conducted by each state varied from a base of 3; Asphalt content, gradation and density, (Alaska) to as many as 19 (Kansas). The overall trend in Connecticut since the implementation of the Superpave Mix Design system in 2004 has been to focus testing efforts on the volumetric properties of the HMA as fabricated in the Superpave gyratory compactor and ensuring the gradation of the HMA aggregates meets the Superpave requirements.

Objective

The objective of this study is to statistically analyze HMA quality assurance data collected by ConnDOT from the 2007, 2008, 2009 and 2010 construction seasons to determine what impact the change in testing requirements may have on the variability and overall quality of the mixes being produced. Furthermore, this analysis will allow ConnDOT to evaluate if the changes to HMA acceptance testing procedures need to be revised further.

Background

In 2004, ConnDOT made the decision to implement a QA approach to improve the quality of HMA used in the construction of transportation facilities in the state. Under QA specifications, target values are specified and quality of the HMA is based on a mathematically derived deviation from the target values and the variability of the product. The QA program allows ConnDOT to invoke payment adjustments based on the quality of the materials and placement provided by the contractor.

The key intended outcome of the QA approach is to have the Contractor practice good overall Quality Control (QC). The Contractor has a direct relationship with the producer of the material who is in the best position to control the quality of the material. The Contractor directly controls the placing of the material which together with material control should produce a quality pavement that performs well for many years.

ConnDOT 2009 Specification Changes

Until the 2009 paving season, ConnDOT had over 26 different QA/QC criteria that HMA producers had to meet (within limits) or face penalties, rejection of material or plant shutdown. The testing of HMA at the production facility is critical to assuring the material meets ConnDOT's specifications for quality. However, the large number of limitations placed on producers may not significantly increase the quality of the mix, but effectively increase the cost to produce the mix due to plant shutdowns, increased resources for testing and lost construction time adjusting mixes to meet a multitude of criteria (which may be redundant). Therefore, ConnDOT reduced the number of quality assurance metrics from 26 to 8 adopted for the 2009 construction season. These eight metrics are: Va (Voids), VMA (Voids Mineral Agg), Gmm (Max Theoretical Gravity), Pb (Percent Binder), four control points for gradation (each mix has four control points that define the mix). The purpose of this change is to reduce the amount of variability on the quality assurance metrics during production, while also reducing the testing burden on ConnDOT and the asphalt producers. However, the true impacts of the changes to quality characteristics on pavement quality characteristics have not been evaluated.

Evaluating the impacts of changing and reducing the number of quality characteristics the HMA being produced will have several significant benefits. The first benefit of this work is to ensure changes made are having the desired outcome of limiting or reducing variability in HMA mixes. The second benefit of this work is to provide feedback and recommendations on what changes ConnDOT could make to enhance the changes to their specifications. The third possible benefit of this analysis is to evaluate how the reduction in controlled metrics impacts the variability in the metrics no longer being controlled. Reducing the number of metrics used, while ensuring the selected metrics produce a material to ConnDOT's specifications, will benefit both ConnDOT and the producers. This project is anticipated to justify changes to the acceptance criteria and provide insight on where adjustments (if any) need to be made.

Literature Review of National HMA Acceptance Specifications

In 2004, the FHWA conducted a national survey of state transportation agencies to determine the current practice for HMA and superpave acceptance (FHWA, 2004). Collecting over 28 HMA and Superpave specifications, FHWA (2004) concluded:

> Examination of the specifications indicated that verification of the mix design is similar for all of the agencies. Additionally, the quality characteristics evaluated for QC and acceptance do not differ substantially from agency to agency. However, there is a significant difference in the quality characteristics evaluated for acceptance. Most of the agencies evaluate the following characteristics: asphalt content; gradation, air voids; VMA; and. in-place density. In addition to these commonly evaluated characteristics, three agencies evaluate mix moisture, VFA, and BSG, and two agencies evaluate TMD, dust-to-asphalt ratio, and *Gmb @ Ndes*. At least one agency evaluates a number of other quality characteristics, such as TSR, sand equivalent, percent crushed aggregate, *Nini*, *Ndes*, and *Nmax*. Four of the eight agencies use smoothness as an acceptance quality characteristic.

In the quote above, the "one agency" that evaluates a number of other quality characteristics was Connecticut. Before the 2009 specification change Connecticut validated mix designs using the following properties: gradation, asphalt content, voids @ *Ndes*, VMA, VFA, *Gmm @ Ndes* and *Nmax*, *Gmb*, *Gse*, TSR, *Ndes*, *Nini*, *Nmax*, recycled asphalt pavement (RAP) gradation, fine aggregate angularity (FAA), coarse aggregate angularity (CAA), sand equivalent, and dust-to-asphalt ratio.

In addition, the FHWA (2004) report indicated gradation, asphalt content, air voids, in-place density, and smoothness were commonly used for pay factors. The specification changes made in 2009 have worked to reduce the number of variables tested. This report will investigate the impacts on mix variability due to those changes.

Survey of New England HMA Acceptance Specifications

As part of this research project, a survey was created to solicit information from the New England states and New York State regarding their quality control and Assurance/Acceptance criteria for HMA. A copy of the survey, response and comments can be found in Appendix A. Tables 1 and 2 summarize the survey responses received for quality control and assurance/acceptance respectively. In the survey, respondents were allowed to write comments about their response. Many gave more detail about the specific criteria or the acceptable tolerances for each of their criteria. The comments from each state can be found in Appendix A.

Table 1: Quality Control Survey Responses

State Agency		Maine DOT	MassDOT, Highway Division	NHDOT	NY State DOT
Who is responsible for Quality Control in your state?		Contractor	Contractor	HMA Producer	HMA Producer
Are the following variables required to be reported as part of your state's Quality Control Program?	Gradation	Yes	Yes	Yes	Yes
	Asphalt Content (Pb)	Yes	Yes	Yes	Yes
	Voids in the Mineral Aggregate (VMA)	Yes	Yes	No	Yes
	Voids filled with Asphalt (VFA)	Yes	Yes	No	Yes
	Total percent Air Voids (Va)	Yes	Yes	No	Yes
	Hveem Stability	No	No	No	No
	Marshall Stability	No	No	No	No
	Marshall Flow	No	No	No	No
	Dust-to-asphalt Ratio	Yes	No	No	No
	Maximum Specific Gravity (Gmm)	Yes	Yes	Yes	Yes
	Bulk Specific Gravity (Gmb)	Yes	Yes	No	Yes
	Effective Specific Gravity (Gse)	Yes	No	No	No
	Blended Specific Gravity of the Blended Aggregate (Gsb)	Yes	No	No	No
	Moisture Content	No	No	No	Yes
	Binder Temperature	No	No	No	No
	Liquid Limit	No	No	No	No
	Plastic Index	No	No	No	No
	Fractured Faces	No	No	Yes	No
	Percent Binder Absorbed (Pba)	No	No	No	No
	Indirect Tensile Strength (ITS)	No	No	No	No
	Tensile Strength Ratio (TSR)	No	No	No	No
	Percent Compaction at Initial # of Gyrations (PD@Ni)	Yes	No	No	No
	Percent Compaction at Design # of Gyrations (PD@Nd)	Yes	No	No	Yes
	Percent Compaction at Maximum # of Gyrations (PD@Nm)	Yes	No	No	No
	In Place Density (Cores)	Yes	Yes	Yes	Yes
	In Place Density (Nuke Gage)	Yes	No	No	Yes
	Other			Temperature	
What sieves are controlled?	#200	Yes	Yes	Yes	Yes
	#100	Yes	No	No	No
	#50	Yes	No	No	No
	#30	Yes	No	No	No
	#16	Yes	No	Yes	No
	#8	Yes	Yes	Yes	Yes
	#4	Yes	Yes	Yes	Yes
	3/8"	Yes	No	Yes	No
	1/2"	Yes	No	Yes	Yes
	3/4"	Yes	No	Yes	No
	1"	Yes	No	No	No
	1 1/2"	Yes	No	No	No
	Other			Asph. Binder	1/8"

In terms of QC, Maine is the only state that controls over all twelve sieves, while MassDOT only controls three sieves. All states control gradation, Pb, Gmm, and in-place density with cores. The majority of states surveyed, also control for VMA, VFA, Va and Gmb.

Table 2: Quality Assurance/Acceptance Survey Responses

State Agency		Maine DOT	MassDOT, Highway Division	NHDOT	NY State DOT
Who is responsible for Quality Assurance/Acceptance in your state?		State DOT	State DOT	State DOT	State DOT
Are the following variables required to be reported as part of your state's Quality Assurance/ Acceptance Program?	Gradation	Yes	Yes	Yes	Yes
	Asphalt Content (Pb)	Yes	Yes	Yes	Yes
	Voids in the Mineral Aggregate (VMA)	Yes	Yes	No	Yes
	Voids filled with Asphalt (VFA)	Yes	Yes	No	Yes
	Total percent Air Voids (Va)	Yes	Yes	Yes	Yes
	Hveem Stability	No	No	No	No
	Marshall Stability	No	No	No	No
	Marshall Flow	No	No	No	No
	Dust-to-asphalt Ratio	Yes	No	No	No
	Maximum Specific Gravity (Gmm)	Yes	Yes	Yes	Yes
	Bulk Specific Gravity (Gmb)	Yes	Yes	Yes	Yes
	Effective Specific Gravity (Gse)	Yes	No	No	No
	Blended Specific Gravity of the Blended Aggregate (Gsb)	Yes	No	No	No
	Moisture Content	Yes	No	No	Yes
	Binder Temperature	No	No	No	No
	Liquid Limit	No	No	No	No
	Plastic Index	No	No	No	No
	Fractured Faces	No	No	No	No
	Percent Binder Absorbed (Pba)	Yes	No	No	No
	Indirect Tensile Strength (ITS)	No	No	No	No
	Tensile Strength Ratio (TSR)	No	No	No	No
	Percent Compaction at Initial # of Gyrations (PD@Ni)	Yes	No	No	No
	Percent Compaction at Design # of Gyrations (PD@Nd)	Yes	No	No	Yes
	Percent Compaction at Maximum # of Gyrations (PD@Nm)	Yes	No	No	No
	In Place Density (Cores)	Yes	Yes	Yes	Yes
	In Place Density (Nuke Gage)	No	No	No	Yes
	Other			Thickness	
What sieves are controlled?	#200	Yes	Yes	Yes	Yes
	#100	Yes	No	No	No
	#50	Yes	No	No	No
	#30	Yes	No	No	No
	#16	Yes	No	Yes	No
	#8	Yes	Yes	Yes	Yes
	#4	Yes	Yes	Yes	Yes
	3/8"	Yes	No	Yes	No
	1/2"	Yes	No	Yes	Yes
	3/4"	Yes	No	Yes	No
	1"	Yes	No	No	No
	1 1/2"	Yes	No	No	No
	Other			asph. binder	1/8"

With respect to Quality Assurance/Acceptance, the results for gradations are identical to Quality Control. For the other variables there are some notable differences between Quality Control and Quality Assurance/Acceptance. For example, all states control gradation, Pb, Va, Gmm, Gmb, and in-place density with cores. The majority of states surveyed also control for VMA and VFA. NY State Department of Transportation (NYDOT) is the only responding state transportation agency that also uses nuclear gages for in-place density measurements.

When evaluating the 2009 changes made to ConnDOT's QA/QC programs for HMA, it appears the ConnDOT program is comparable to the programs established in other New England states. Gmb is the only standard variable that other states are controlling for that Connecticut is not. ConnDOT is also controlling four different sieves which is consistent with the programs at NYDOT and the Massachusetts Department of Transportation (MassDOT).

Data Collection

As part of ConnDOT's HMA QA/QC program, vendors must submit test results to ConnDOT as well as samples of material for testing. The analysis of variance conducted in this research is based on the data collected as part of the QA/QC database in 2007, 2008, 2009 and 2010. The database obtained from ConnDOT contains: job mix formula (JMF) specifications for each mix over time, vendor, mix type, date of data collection, technician and project ID. In terms of testing, the database reports:

- **Percent passing each of the sieves**
  - (#200,#100,#50, #30, #16, #8, #4, 3/8", ½", ¾", 1", 1 ½", 2")
- **Pb**- Percent binder
- **Gmm** - Theoretical Maximum Specific Gravity (AASHTO T-209)
- **Gse**- Effective Specific Gravity
- **Gsb**- Bulk Specific Gravity of the Blended Aggregate
- **Gb**- Specific Gravity of Asphalt Binder
- **Va**- Percent Air Voids
- **VMA**- Voids in the Mineral Aggregate
- **Pbe**- Effective Percent Binder
- **Gmb**- Bulk Specific Gravity of the Mix (AASHTO T-166)
- **VFA**- Voids Filled with Asphalt
- **Pba**- Percent Absorbed Asphalt
- **PD@Ni**- Percent compaction at the initial number of gyrations
- **PD@Nd**- Percent compaction at the design number of gyrations
- **PD@Nm**- Percent compaction at the maximum number of gyrations

As described above, the changes to ConnDOT's QA/QC program went into effect for the 2009 paving season. Therefore, the data obtained from ConnDOT contains two years before the specification change and one year after the specification change. This data range will allow for an analysis of change in HMA variability with respect to changes in specifications.

Data Analysis

The QA/QC data obtained from ConnDOT were compiled into a database and then checked for accuracy and consistency. Through the data evaluation process, the research team discovered there were observations in the dataset which were unrealistic and needed to be removed before analysis could begin. For example, one data row in the 2008 dataset contained a VFA value of -8.125. A negative VFA value is not acceptable (or possible) so that record was removed from the dataset. Another type of error was found in the 2008 dataset where

Gmb values were reported to be 2,560 and 128.1. These records were also removed from the analysis. In total, 40 of the 10,857 records were discovered to have an unrealistic or erroneous variable reported in the dataset. These 40 records were removed from the final dataset used in this analysis leaving the final dataset to include 10,817 sample sets from 2007 to 2010. Table 3 contains a breakdown of number of records contained in each year and the number removed. The 2010 dataset had 32 records removed due to a typo in the Gsb value (reported as 22.282) for an entire project (24 records). The data were not removed based on outlier status. Since the objective of this analysis was to determine the variability of the pavement mix, removal of outliers would eliminate a valid data point from the variability analysis which could have a significant impact on the variability statistic. This analysis makes the assumption that test were conducted using standard practice and only errors in the dataset were removed, not valid tests that proved to be outliers.

Table 3. Summary of Records Removed for Analysis

Year	# of Records Provided	# of Records Used in Analysis	# of Records Removed
2007	2437	2436	1
2008	2918	2915	3
2009	2715	2711	4
2010	2787	2755	32

Data analysis for this project were conducted at different levels. The "**State Level"** refers to a mix based analysis regardless of who produced the mix. The "**Mix Level"** refers to a mix specific analysis based on different producers. The third level was conducted at a "**Producer Level**" where a constant mix was selected for a single producer that spanned all four years of interest.

Results and Conclusions

State Level

Using the reduced dataset described above, a basic analysis was conducted to determine the yearly standard deviation of each mix produced in the state regardless of the producer. Appendix B contains a series of plots for each variable contained in the data provided by ConnDOT. For these plots, each square data point is a specific mix. The trend line connecting each year represents the overall weighted mean standard deviation for all the mixes within a year. The weighted mean is used because some mixes may have hundreds of tests per year where less common mixes may only have a couple tests in a year. Therefore, the weighted average standard deviation line may not always fall in the center of the range of data points for that year. This trend line will allow for a quick visual analysis of temporal trends in standard deviation. The plotting of individual mix data points allows for an analysis of how the range in variability increases or decreases over time. When analyzing all the mixes in the state as a whole, none of the changes in variability or changes in the range of variability can be considered statistically significant. Therefore, the slight changes reported below, good or bad, may or may not be attributed to the changes in specifications made in 2009. This section will outline the trends found in each variable reported by ConnDOT.

Percent Binder (Pb)

The plot for percent binder is shown as an example. The plots for the remaining variables can be found in Appendix B. The Y-axis is the standard deviation of percent binder. The X-axis contains the year in which the sample was obtained and tested. The 2009 and 2010 specimens were tested under the new, reduced control points for payment. Over all four years, the range of standard deviations remains fairly constant. In 2007 and 2009, there were two mixes that had a significantly higher standard deviation than the rest of the mixes. The two mixes were, #4 Superpave Level 2 at 0% RAP and 25.0-mm Level 2 HMA at 15% RAP respectively. Overall, there does not appear to be a reduction in Pb variability or due to the 2009 changes in specifications. However, the 2009 range of variability is smaller in 2009 than in 2007 and 2008. Moreover, the 2010 range appears as if it would be even smaller than the previous years, except for the maximum and minimum data points for two individual mixes, seen as separated from the group on the top and bottom.

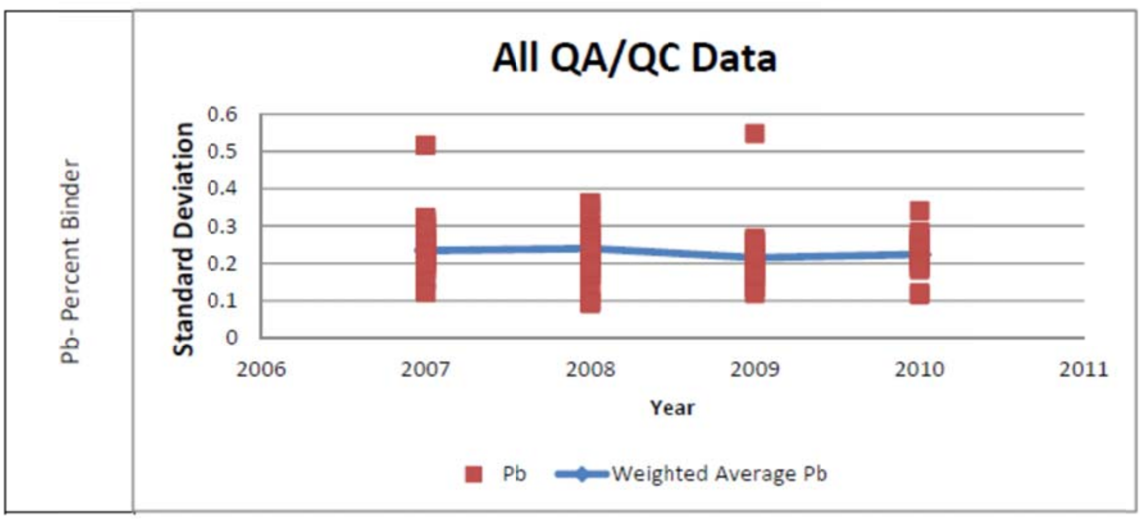

Figure 1: Percent Binder Analysis at the State Level

Theoretical Maximum Specific Gravity (Gmm)

For Gmm, the temporal trend indicates there is little to no change in the range of variability seen from 2007 to 2010. However, in 2010, one should note that the lower limit on standard deviations (i.e., more consistent mix) has increased. The associated trend for weighted average indicates that, in 2010, the average standard deviation was at a minimum for the four years studied. This indicates there is a reduction in variability of mixes in 2010 even though the range of variability is similar to the previous years. However, this is not a statistically significant reduction in variability but a localized trend.

Effective Specific Gravity (Gse)

Similar to Gmm, Gse had a reduction in variability in 2010 while the range of variability remained largely unchanged, with the exception of the lower limit increase noted in the Gmm discussion.

Bulk Specific Gravity of the Blended Aggregate (Gsb)

Similar to Gmm and Gse, Gsb had a reduction in variability in 2010 while the range of variability remained largely unchanged, with the exception of the lower limit increase noted in the Gmm and Gse discussion.

Percent Air Voids (Va)

The analysis of Va indicates that there is a temporal trend which shows a slight increase in mix variability as the years progress. However, The Va plot in Appendix B indicates the range of variability is decreasing over time. Therefore, we can conclude that 2010 had the largest mean variability in material produced, but it was the most consistent mix produced over the last four years in terms of Va. The overall increase in mean Va is very small, less than 0.2 percent; while the reduction in the range in variability is much more significant at almost 1 percent. Whether these changes can be attributed to the 2009 specification change is debatable.

Voids in the Mineral Aggregate (VMA)

An analysis of VMA data over the four-year period indicates that 2007 had the lowest average variability, but the largest range in variability. Overall, there is an increasing trend in mean variability. However, this is not a significant increase in variability. There is also a noticeable trend in decreasing range of variability with an increase in time.

Effective Percent Binder (Pbe)

The plot for Pbe indicates that there is no net change in average variability over time.

Bulk Specific Gravity of the Mix (Gmb)

For Gmb, there is no discernible trend with respect to range or average variability over time.

Voids Filled with Asphalt (VFA)

There is an overall slight increase in average VFA, but there is an obvious decrease in the range of variability over time, most notably in 2010, where the variability is approximately half that of the previous years.

Percent Absorbed Asphalt (Pba)

For percent absorbed asphalt, there is no discernable temporal pattern in variability.

Percent Compaction

The three variables that describe compaction as a function of gyrations indicate that there may be an overall reduction in the range of variability, but there is not a consistent overall decrease in mean variability.

Percent passing each of the sieves

When investigating the variability of percent aggregate passing each of the sieves there is no discernable pattern in rage or average variability with respect to time. However, for the #200, #100, and #50 sieve, there is an overall increase in mean variability with an analysis of the #50 showing the most significant increase in variability in 2010. Another notable observation is that, in 2009 and 2010, the minimum standard deviation is increasing from zero for many of the sieves with an opening less than the #4. This could indicate producers are making changes to the fines in the mix to meet other specification requirements. These changes in the fine aggregate percentages could be driving the reduction in variability seen in VFA and Pbe.

Mix Level

A mix level analysis was conducted for a select subset of mixes. For a mix to be selected for analysis in this analysis, it needed to have a minimum of five samples tested in each of the four years. Mixes, with and without RAP, were treated as different mixes, as were mixes with different percentages of RAP. 2007 and 2008 contained few, if any, mixes with RAP. This resulted in only 3 of the 40 different mixes in the dataset being selected for a more in-depth analysis. These mixes were:

- 12.5-mm Level 2 HMA at 0% RAP;
- 12.5-mm Level 3 HMA at 0% RAP; and,
- 9.5-mm Level 2 HMA at 0% RAP.

One other mix, 12.5-mm Level 2 HMA at 10% RAP, fit these criteria. However, there was only one producer tested in 2010. Since the temporal trend in variability for 2010 should not be based on a single vendor, it was removed from further analysis due to the limited sampling done in 2010. Therefore, each data point is the variability of a vendor that had at least five samples tested in that year for the specific mix being analyzed.

Similar to the analysis that was conducted above, plots were generated for each of the variables in the ConnDOT dataset. However, for these plots, each data point represents the standard deviation for a single producer for the respective mix. Therefore, these plots will indicate the variability of individual producers and the range of variability for the mix on a producer scale. These plots may be a better indicator of variability since they are mix- and producer-specific variability. For example, if Producer A and Producer B have a very low variability for their 12.5-mm mix, once you combine the two producers' data, the overall variability of the mix may increase due to differences in job mix formula specifications and aggregate properties.

12.5- mm Level 2 HMA at 0% RAP

Plots for each individual variable can be found in Appendix C, the plot for percent binder is included as an example plot for discussion. The variability for each producer on the 12.5-mm level 2 HMA mix with 0% RAP indicates the overall variability is low for each producer (less than 0.25%). There is also no discernable trend with time, and therefore, with specification changes made in 2009. This trend with no change over time can also be seen in VMA, Pbe, and Pba.

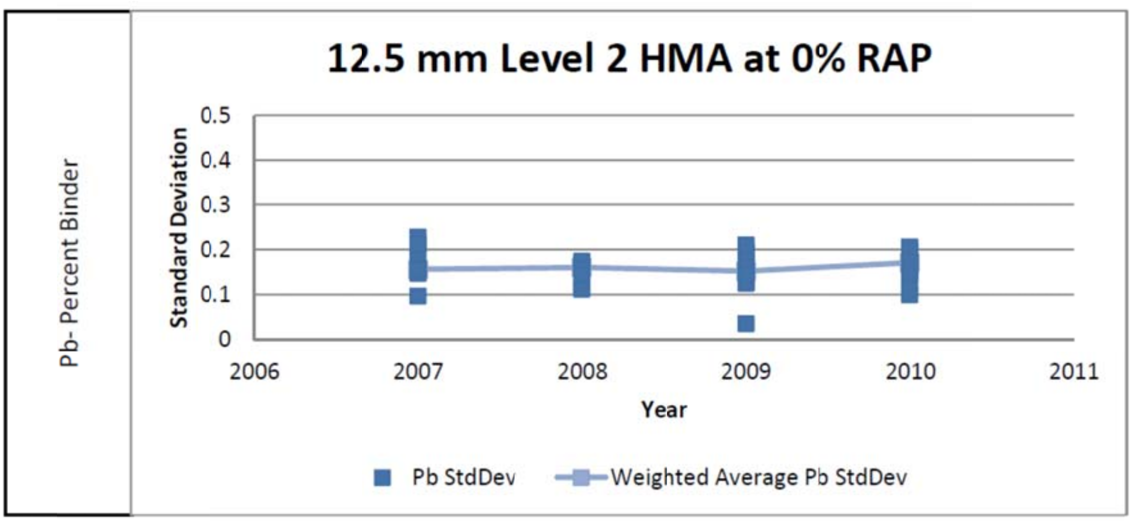

Figure 2: PB Analysis for 12.5-mm Level 2 HMA 0% RAP

Of the remaining variables, there are two variables that show a slight increase in variability, Gmm and Gse. While these increases are not statistically significant, they do indicate variability for these variables may be increasing, if even on a small scale.

For the remaining variables, Gsb, Va, Gmb, VFA, PD@Ni, PD@Nd, PD@Nm, there is an overall decrease variability. This could indicate that the specification changes made in 2009 are allowing producers to create a mix that is more consistent across more variables.

An investigation into percent aggregate passing each sieve indicates there is no temporal trend in variability in aggregate composition.

12.5-mm Level 3 HMA at 0% RAP

The variability plots for the 12.5-mm Level 3 HMA with 0% RAP can be found in Appendix D. Overall, there appears to be little change in variability or range of variability over time. The only variable that indicates there may be an increase in variability is Pb, while Gmm and VFA have a slight decrease in variability. Variability of Gse, Gsb, Va, VMA, Pbe, Gmb, Pba, PD@Ni, PD@Nd, PD@Nm remains fairly constant overtime. This indicates there is no clear trend with these variables for this mix.

With respect to aggregate composition, there are a few sieve sizes that show a slight increase in variability in the 2010 season. The #50 sieve and the # 8 sieves show a slight increase in variability for 2010. The #4 sieve for this mix has a much larger variability and range of variability for 2010 when compared to previous years. However, the differences seen in the plots are not statistically significant differences and, therefore, cannot be used to indicate a valid change in variability over time.

9.5-mm Level 2 HMA at 0% RAP

Plots describing the variability for individual parameters of the 9.5-mm Level 2 HMA with 0% RAP can be found in Appendix E. Overall, there appears to be a slight decrease in variability for this mix. The following variables show a decrease in variability: Pb; Va; VMA; Gmb; VFA; PD@Nd; PD@Ni; and, PD@Nm. Furthermore, there is a reduction in the range of variability for VFA. However, when looking at the plots for gradation, only the #200, #100 and #50 variables indicate no change in variability. The rest of the sieves between #30 and ½" indicate variability is increasing. This could indicate that producers are making changes to the gradations in order to satisfy the other acceptance criteria. However, the variability in percent passing are relatively small (< 1%) and are not statistically significant.

Producer Level

Based on the results of the variability analysis above, a final analysis was conducted to determine if the variability for individual producers systematically decreased over time based on the specification changes. Similar to the previous analysis, the results of this investigation were not statically significant. Therefore, temporal trends in variability over time were investigated using a visual evaluation. The plots of each variable for four different producers can be found in Appendix F.

The plots in Appendix F indicate that there is no discernible pattern in variability with respect to time or all producers. However, if the trends for Producer D are examined, it appears that 2008 contained the largest variability in tested samples, followed by 2009 and 2010 with much lower variability. The same can be said for Producer C. While there are fluctuations in variability over time for each producer, these fluctuations do not seem to be tied to the specification changes made in 2009.

Summary and Conclusions

Based on the literature review, regional survey of DOTs and the analysis conducted on QA/QC data obtained from ConnDOT for 2007 through 2010, it does not appear that changes made in 2009 have negatively impacted the quality of the pavement that is being produced in the state. Based on an ANOVA analysis, there is no statistical difference in pavement produced in 2007, 2008, 2009 and 2010. This is very encouraging news for ConnDOT, indicating that the pre-2009 levels of testing and added expense of additional testing was not necessary to produce the same mix that is being produced today.

ConnDOT has also reported that, as a result of the specification changes in 2009, plant shutdowns have decreased significantly. This prevents costly delays in pavement placement and reduces the cost of asphalt since producers will no longer include contingencies for a plant shutdown. It is anticipated that the reduced amount of testing and elimination of plant shutdowns should provide the ConnDOT with a cheaper cost per ton of HMA when normalized for the variable price of asphalt binder. Furthermore, the elimination of plant shutdowns will save ConnDOT and the traveling public costly project delays due to material not passing unnecessary QA metrics.

References

ConnDOT. 2009. QA Program for Materials Acceptance and Assurance Testing Policies and Procedures. http://www.ct.gov/dot/lib/dot/documents/dpublications/dmt-manual_2009_v2.pdf. Last accessed on March 5th 2012.

SC-M-400 (05/10). Supplemental Technical Specification for March 3, 2010. Hot Mix Asphalt (HMA) Quality Assurance. SCDOT Designation: SC-M-400 (05/10). http://www.scdot.org/doing/pdfs/sup_tech_specs/SC-M-400.pdf. Accessed on May 18, 2011.

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Appendix A

New England HMA Specification Survey

Sample of Survey

Coments from Survey

Sample of the Online Survey

HMA Acceptance Criteria

CTI
CAP Lab-Connecticut Advanced Pavement Laboratory
UCONN

The purpose of this survey is to determine how New England states and New York conduct quality assurance for HMA.

Welcome to our HMA Acceptance Criteria Survey. Thank you in advance for taking 5 minutes to fill out this very brief survey.

Agency

* **Which state agency do you work for?**

HMA Acceptance

* **Does your state have a HMA QA/QC specification?**

- Yes
- No

* **Who is responsible for Quality Control in your state?**

Choose one of the following answers

- State DOT
- Contractor
- HMA Producer
- Other:

* **Please check which of the following variables are required to be reported as part of your state's Quality Control Program?**

If possible use the comment section to the right of each variable to briefly describe the allowed variation from the job mix formula.

Check any that apply

- Gradation
- Asphalt Content (Pb)
- Voids in the Mineral Aggregate (VMA)
- Voids filled with Asphalt (VFA)
- Total percent Air Voids (Va)
- Hveem Stability
- Marshall Stability
- Marshall Flow
- Dust-to-asphalt Ratio
- Maximum Specific Gravity (Gmm)
- Bulk Specific Gravity (Gmb)
- Effective Specific Gravity (Gse)
- Blended Specific Gravity of the Blended Aggregate (Gsb)
- Moisture Content
- Binder Temperature
- Liquid Limit
- Plastic Index
- Fractured Faces
- Percent Binder Absorbed (Pba)

- Indirect Tensile Strength (ITS)
- Tensile Strength Ratio (TSR)
- Percent Compaction at Initial # of Gyrations (PD@Ni)
- Percent Compaction at Design # of Gyrations (PD@Nd)
- Percent Compaction at Maximum # of Gyrations (PD@Nm)
- In Place Density (Cores)
- In Place Density (Nuke Gage)
- Other:

* **What sieves are controlled?**

Check any that apply

- #200
- #100
- #50
- #30
- #16
- #8
- #4
- 3/8"
- 1/2"
- 3/4"
- 1"
- 1 1/2"
- Other:

* **Who is responsible for Quality Assurance in your state?**

Choose one of the following answers

- State DOT
- Contractor
- HMA Producer
- Other:

* **Which of the following variables are required to be reported as part of your state's Quality Assurance (Acceptance) Program?**

If possible use the comment section to the right of each variable to briefly describe the allowed variation from the job mix formula.

Check any that apply

- Gradation
- Asphalt Content (Pb)
- Voids in the Mineral Aggregate (VMA)
- Voids filled with Asphalt (VFA)
- Total percent Air Voids (Va)
- Hveem Stability
- Marshall Stability
- Marshall Flow
- Dust-to-asphalt Ratio
- Maximum Specific Gravity (Gmm)
- Bulk Specific Gravity (Gmb)
- Effective Specific Gravity (Gse)
- Blended Specific Gravity of the Blended Aggregate (Gsb)
- Moisture Content
- Binder Temperature
- Liquid Limit
- Plastic Index
- Fractured Faces
- Percent Binder Absorbed (Pba)
- Indirect Tensile Strength (ITS)

- [ ] Tensile Strength Ratio (TSR)
- [ ] Percent Compaction at Initial # of Gyrations (PD@Ni)
- [ ] Percent Compaction at Design # of Gyrations (PD@Nd)
- [ ] Percent Compaction at Maximum # of Gyrations (PD@Nm)
- [ ] In Place Density (Cores)
- [ ] In Place Density (Nuke Gage)

Other:

* **What sieves are controlled?**

Check any that apply

- [ ] #200
- [ ] #100
- [ ] #50
- [ ] #30
- [ ] #16
- [ ] #8
- [ ] #4
- [ ] 3/8"
- [ ] 1/2"
- [ ] 3/4"
- [ ] 1"
- [ ] 1 1/2"

Other:

Submit

Exit and clear survey

Load unfinished survey Resume later

Quality Control Comments from 2011 CAPLab HMA Criteria Survey

Which state agency do you work for?		Maine DOT	MassDOT, Highway Division	NHDOT	NY State Department of Transportation
Who is responsible for Quality Control in your state?		Contractor	Contractor	HMA Producer	HMA Producer
Are the following variables required to be reported as part of your state's Quality Control Program?	Gradation	2% on #200, more on larger sieves	depending on sieve sizes		Required to determine eligibility for incentive.
	Asphalt Content (Pb)	.4%	+/- 0.4%	+/-1.0	Required to determine eligibility for incentive.
	Voids in the Mineral Aggregate (VMA)	Minimum only	+/- 1.0%		Reported for QC only.
	Voids filled with Asphalt (VFA)	AASHTO STD.	+/- 5.0%		Reported for QC only.
	Total percent Air Voids (Va)	2.5% to 5.5%	+/- 2.0%		Used for payment adjustment.
	Hveem Stability				
	Marshall Stability				
	Marshall Flow				
	Maximum Specific Gravity (Gmm)	0.03	+/- 0.02		Reported for test results validation.
	Bulk Specific Gravity (Gmb)		+/- 0.022		Reported for test results validation.
	Effective Specific Gravity (Gse)				
	Blended Specific Gravity of the Blended Aggregate (Gsb)	0.04			
	Moisture Content				Test once per day.
	Binder Temperature				
	Liquid Limit				
	Plastic Index				
	Fractured Faces			>50%	
	Percent Binder Absorbed (Pba)				
	Indirect Tensile Strength (ITS)				
	Tensile Strength Ratio (TSR)				
	Percent Compaction at Initial # of Gyrations (PD@Ni)				
	Percent Compaction at Design # of Gyrations (PD@Nd)				Used for payment adjustment.
	Percent Compaction at Maximum # of Gyrations (PD@Nm)				
	In Place Density (Cores)	92.5% to 97.5%	+/- 2.0%	+/-2.0% of spec. limits	For 50 Series compaction - daily 4 cores used for payment adjustment. For 60 Series - first day test section cores used to establish Project Target Density. After first day, cores taken at specified frequency subject to payment adjustment.
	In Place Density (Nuke Gage)	92.5% to 97.5%			For 50 Series compaction - used for QC purpose by contractor. For 60 Series - first day test section cores used to establish Project Target Density for teh gauge. Then gauge used for density monitoring. Gauge is also used for 70 Series compaction method. PTD established using "PEAK" method.
	Other			of Mix, of Surface, of Mat; asphalt binder; thickness	
What sieves are controlled?	#200	+/- 2%		+/-3	Reported for test results validation for non-volumetric mixes and required to determine eligibility for incentive for volumetric mixes.
	#100	+/- 2%			
	#50	+/- 2%			
	#30	+/- 3%			
	#16	+/- 4%		+/-6	
	#8	+/- 4%		+/-7	Required to determine eligibility for incentivef or volumetric mixes.
	#4	+/- 7%		+/-9	Required to determine eligibility for incentive for volumetric mixes.
	3/8"	+/- 7%		12.5mm mix only	
	1/2"	+/- 7%		19mm mix only	Reported for test results validation.
	3/4"	+/- 7%		25mm mix only	
	1"	+/- 7%			
	1 1/2"				
	Other			+/-1.0 or +/-0.8	Reported for test results validation.

Quality Assurance/Acceptance Comments from 2011 CAPLab HMA Criteria Survey

Which state agency do you work for?		Maine DOT	MassDOT, Highway Division	NHDOT	NY State Department of Transportation
Who is responsible for Quality Assurance in your state?		State DOT	State DOT	State DOT	State DOT
Are the following variables required to be reported as part of your state's Quality Assurance/ Acceptance Program?	Gradation	By sieve	depending on sieve sizes		Required to determine eligibility for incentive.
	Asphalt Content (Pb)	+/- 0.4%	+/- 0.4%	+/-1.0	Required to determine eligibility for incentive.
	Voids in the Mineral Aggregate (VMA)	AASHTO for min, no max.	+/- 1.0%		Reported for QA only.
	Voids filled with Asphalt (VFA)	65% -84%	+/- 5.0%		Reported for QA only.
	Total percent Air Voids (Va)	2.5% - 5.5%	+/- 2.0%	+/-2.0% of spec. limits	Used for payment adjustment.
	Hveem Stability				
	Marshall Stability				
	Marshall Flow				
	Maximum Specific Gravity (Gmm)	0.03	+/- 0.02		Reported for test results validation.
	Bulk Specific Gravity (Gmb)	NA	+/- 0.022		Reported for test results validation.
	Effective Specific Gravity (Gse)	NA			
	Blended Specific Gravity of the Blended Aggregate (Gsb)	0.04			
	Moisture Content	NA			Monitor and verify once per day.
	Binder Temperature				
	Liquid Limit				
	Plastic Index				
	Fractured Faces				
	Percent Binder Absorbed (Pba)	NA			
	Indirect Tensile Strength (ITS)				
	Tensile Strength Ratio (TSR)				
	Percent Compaction at Initial # of Gyrations (PD@Ni)	NA			
	Percent Compaction at Design # of Gyrations (PD@Nd)	NA			
	Percent Compaction at Maximum # of Gyrations (PD@Nm)	NA			
	In Place Density (Cores)	92.5% to 97.5%	+/- 2.0%	+/-2.0% of spec. limits	Testing cores and loose mix samples submitted by the contractor.
	In Place Density (Nuke Gage)				Verify the density gauge measurements in the field.
	Other			+/- 15%, but > 1/4"	
What sieves are controlled?	#200	+/- 2%		+/-3	Reported for test results validation for non-volumetric mixes and required to determine eligibility for incentive for volumetric mixes.
	#100	+/- 2%			
	#50	+/- 2%			
	#30	+/- 3%			
	#16	+/- 4%		+/-6	
	#8	+/- 4%		+/-7	Required to determine eligibility for incentivef or volumetric mixes.
	#4	+/- 7%		+/-9	Required to determine eligibility for incentivef or volumetric mixes.
	3/8"	+/- 7%		+/-10 12.5mm only	
	1/2"	+/- 7%		+/-10 19mm only	Reported for test results validation.
	3/4"	+/- 7%		+/-12 25mm only	
	1"	+/- 7%			
	1 1/2"				
	Other			+/-1.0 or +/-0.8	Reported for test results validation.

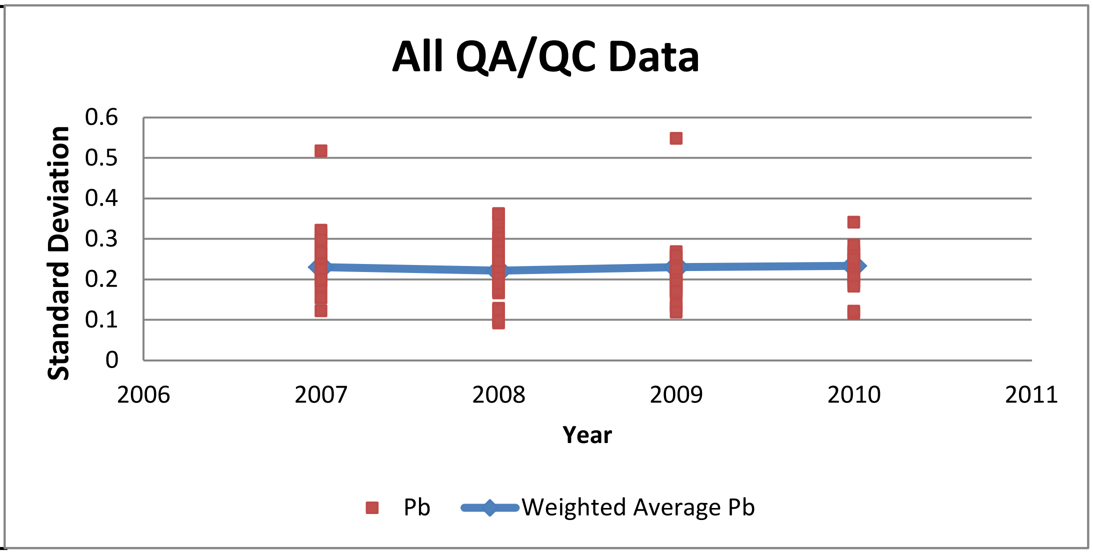
Appendix B

All Mixes

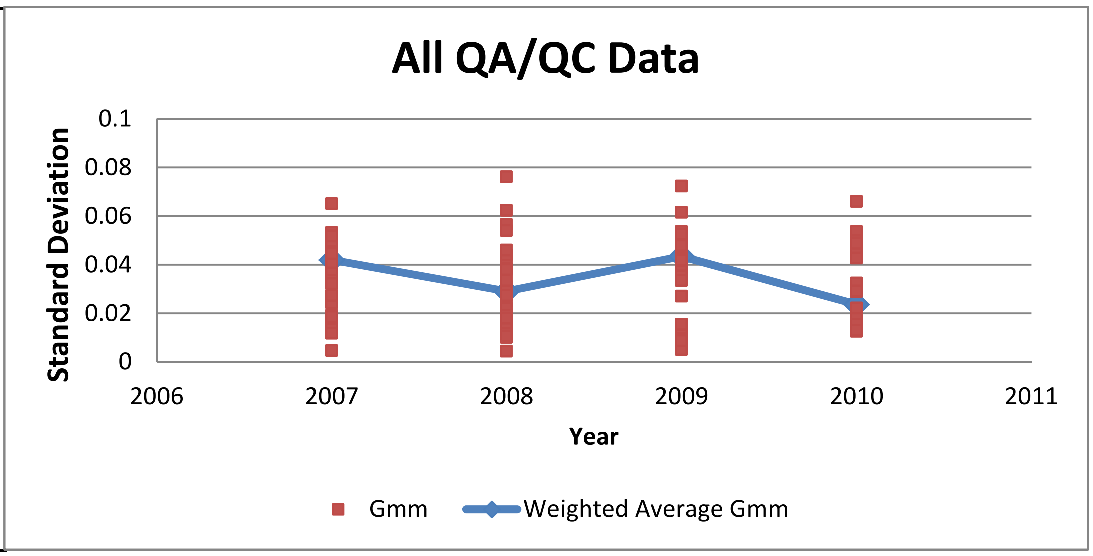
All Vendors

Each data point within each year is a different mix

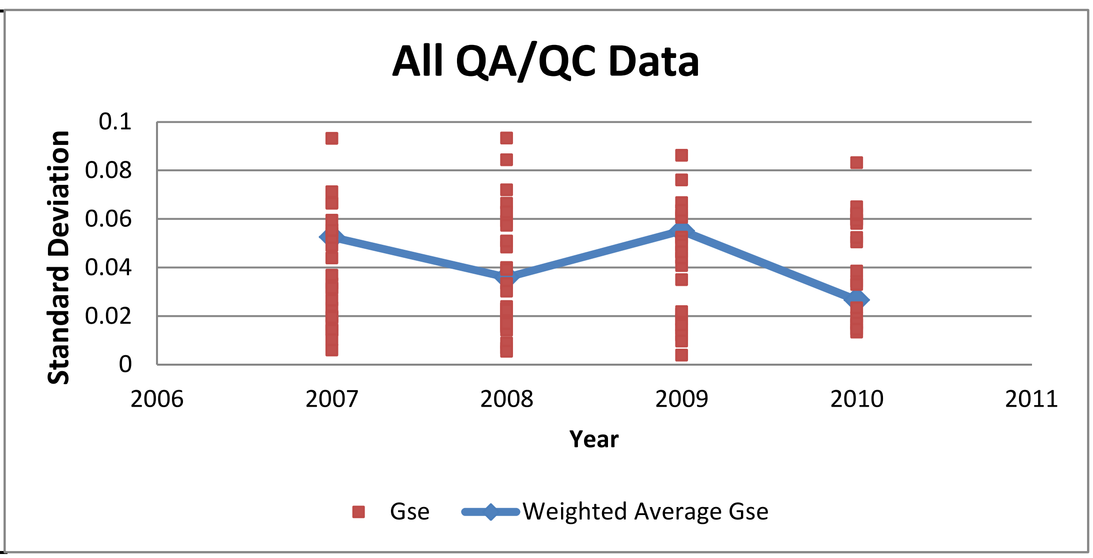
Pb- Percent Binder



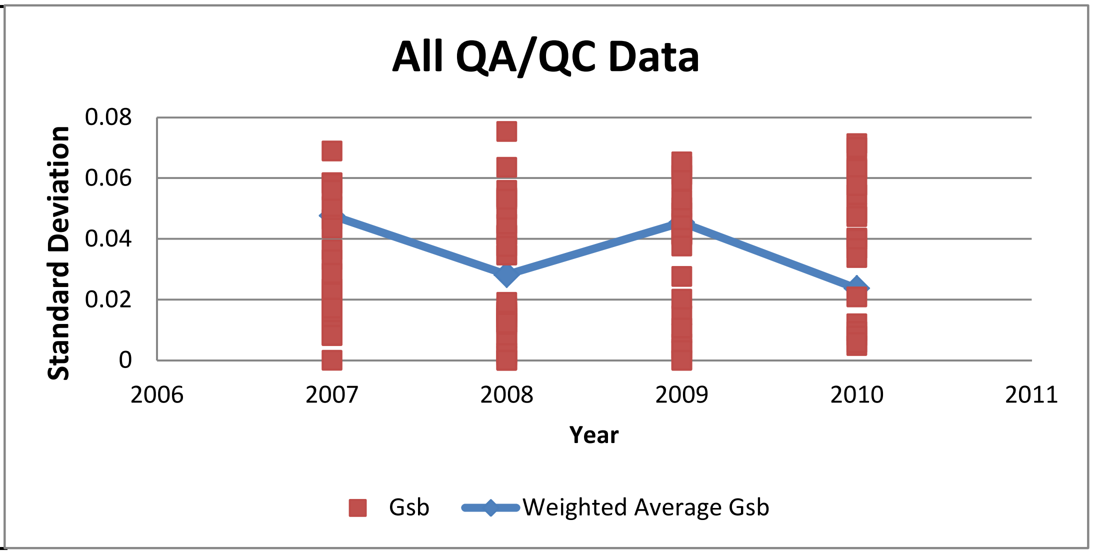
Gmm- Theoretical Maximum Specific Gravity (AASHTO T-209)



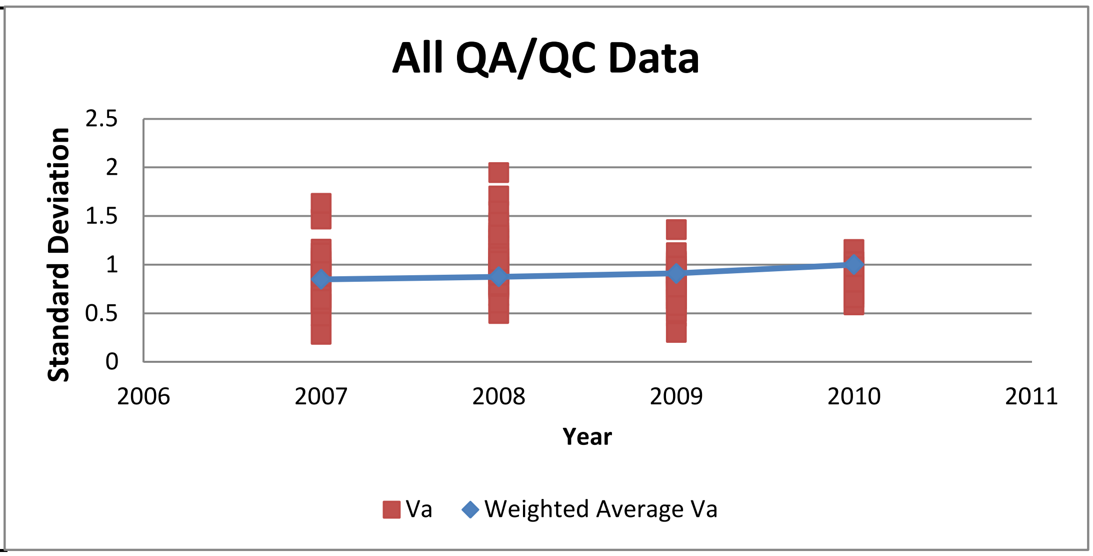
Gse- Effective Specific Gravity



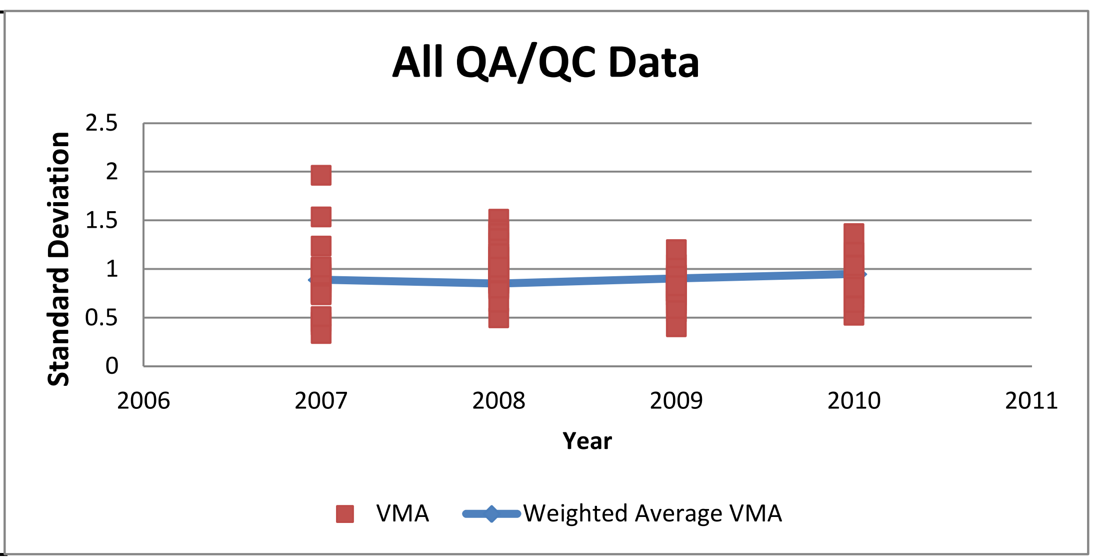
Gsb- Bulk Specific Gravity of the Blended Aggregate



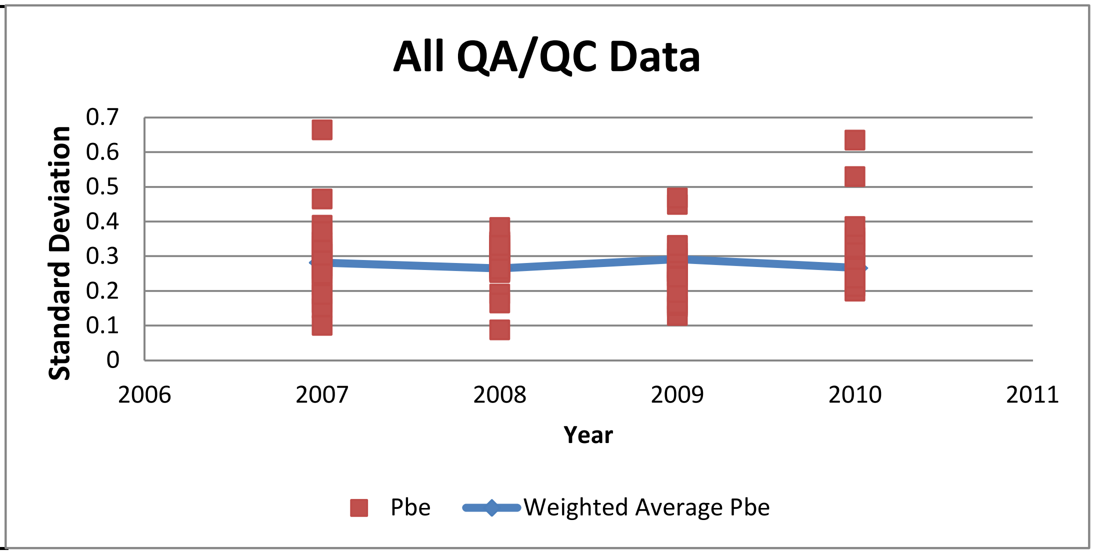
Va- Percent Air Voids



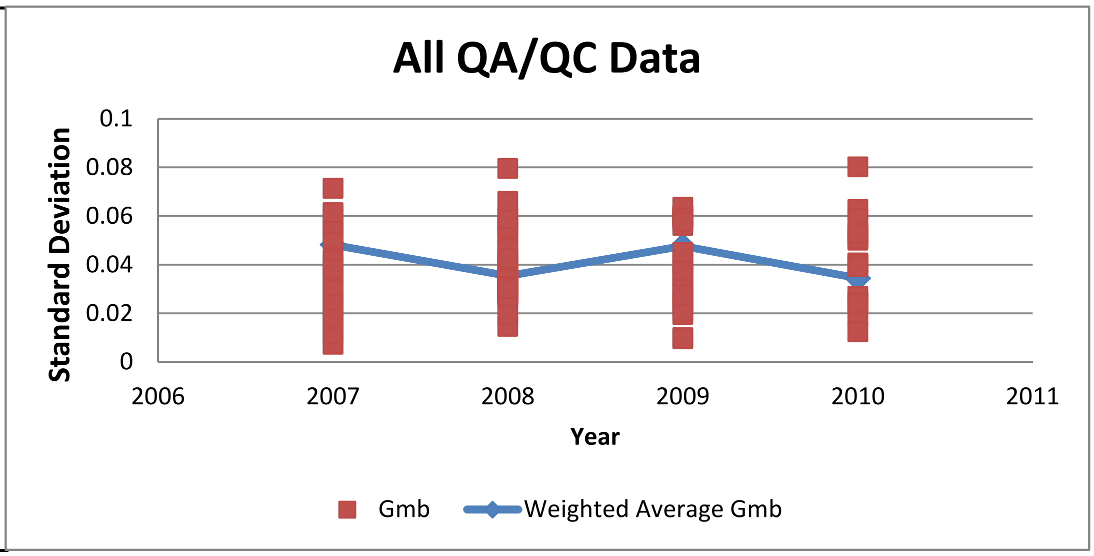
VMA- Voids in the Mineral Aggregate



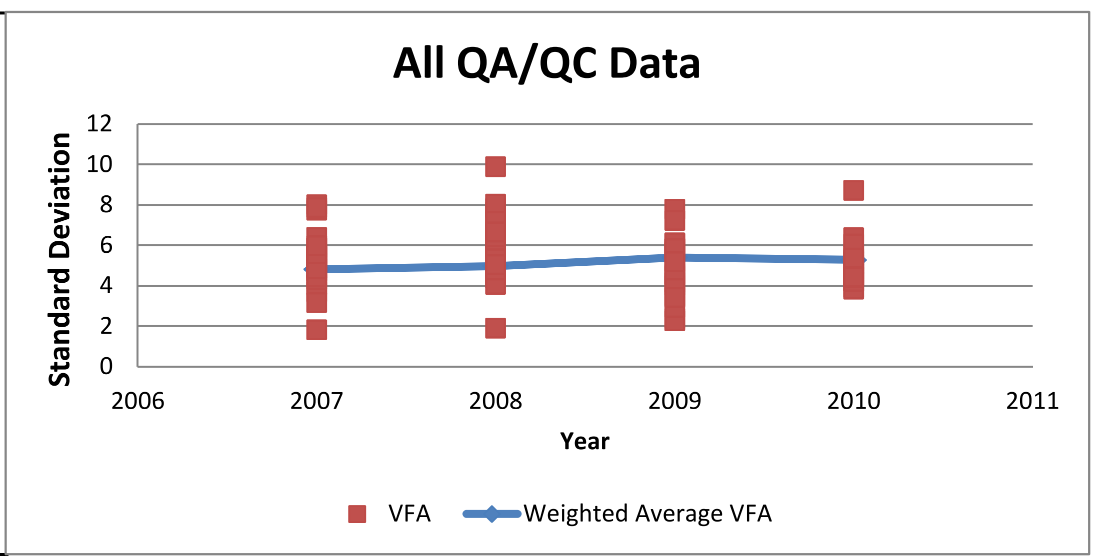
Pbe- Effective Percent Binder



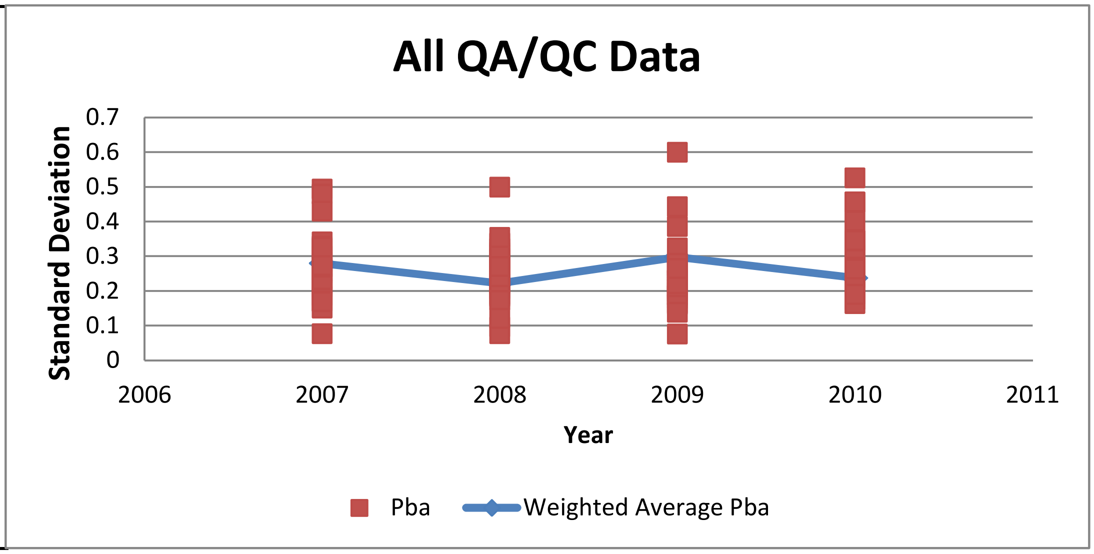
Gmb- Bulk Specific Gravity of the Mix (AASHTO T-166)



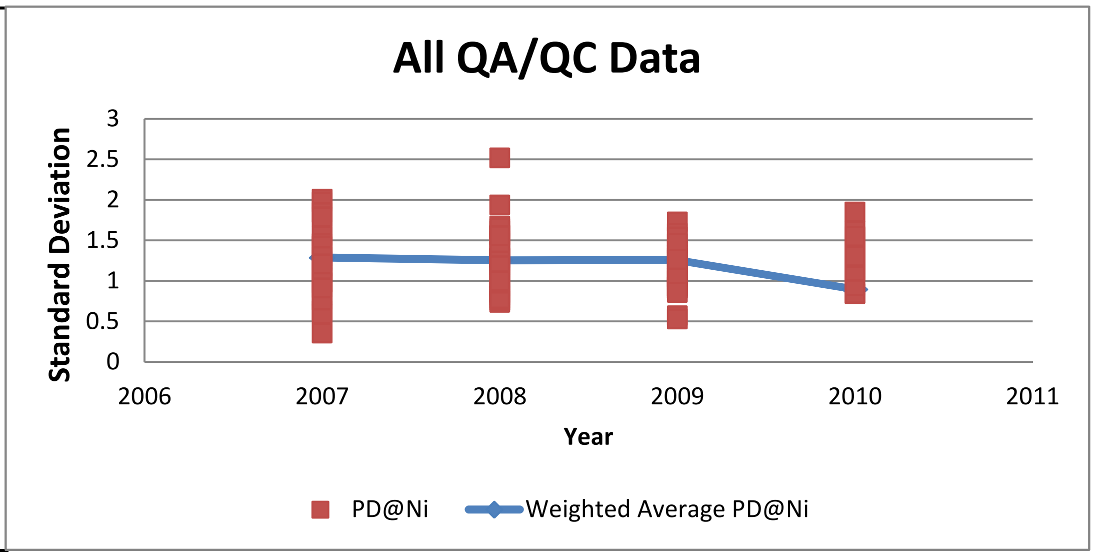
VFA- Voids Filled with Asphalt



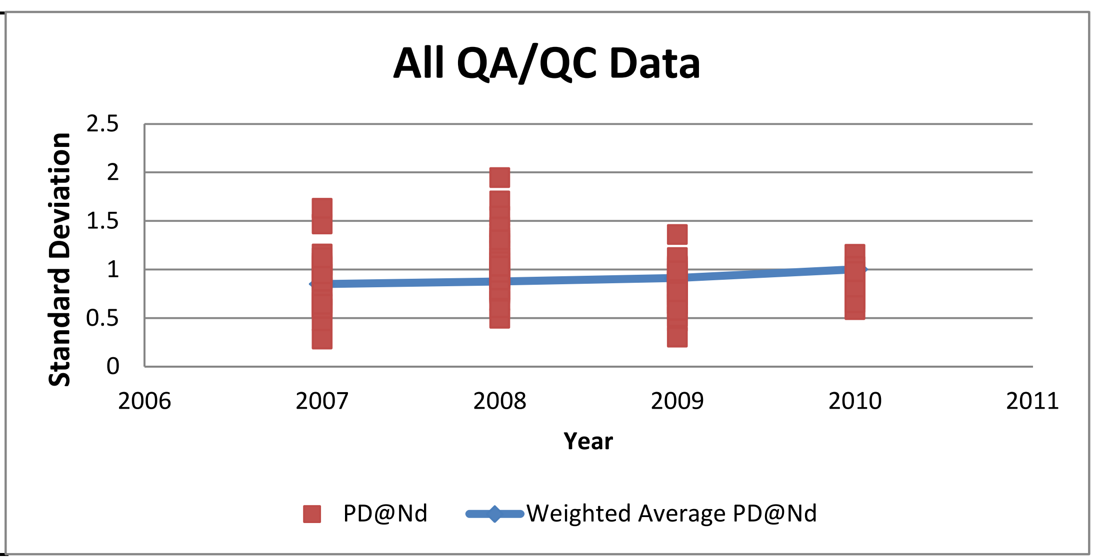
Pba- Percent Absorbed Asphalt



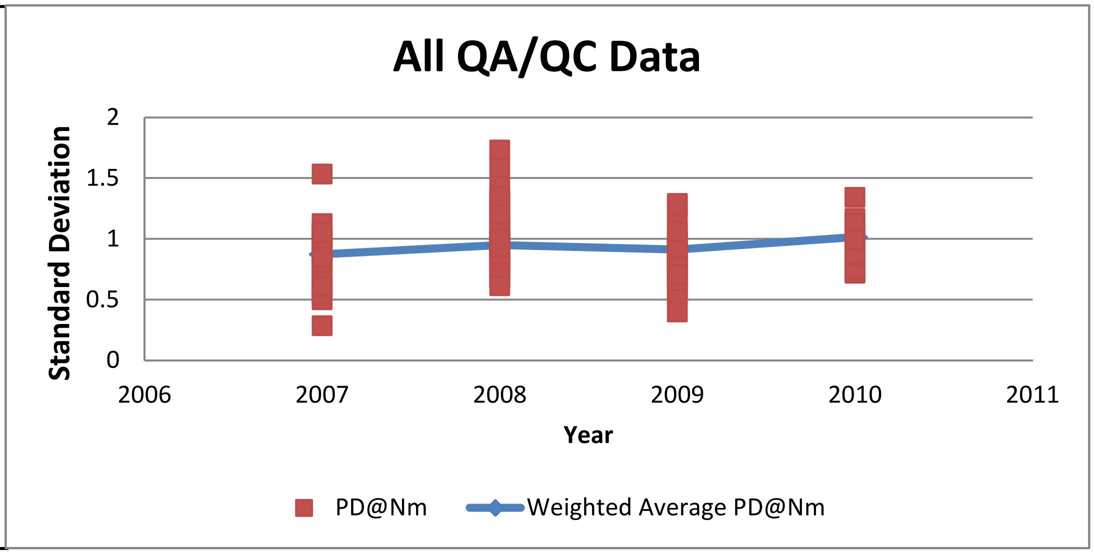
PD@Ni- Percent compaction at the initial number of gyrations



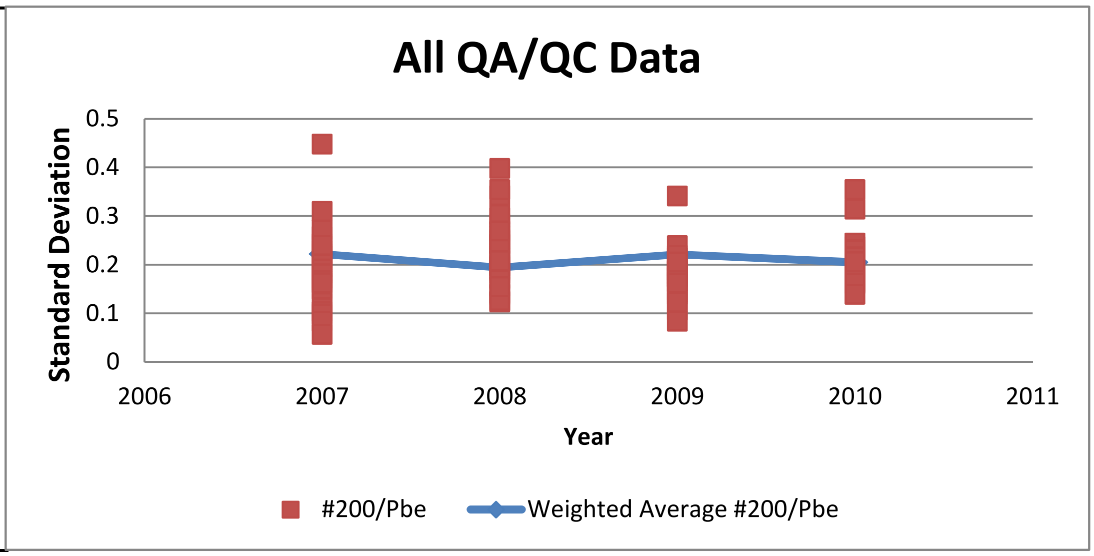
PD@Nd- Percent compaction at the design number of gyrations



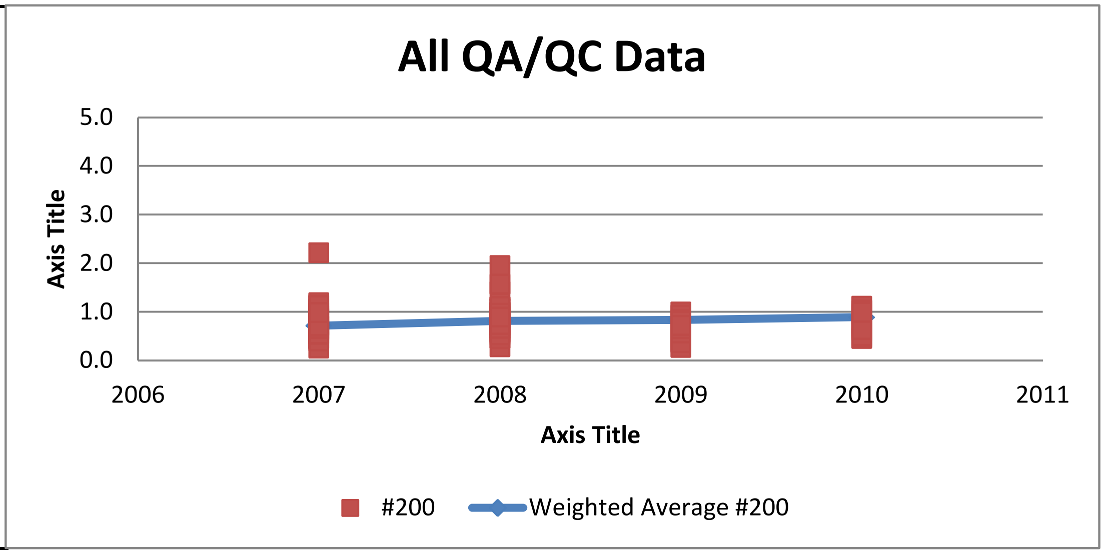
PD@Nm- Percent compaction at the maximum number of gyrations



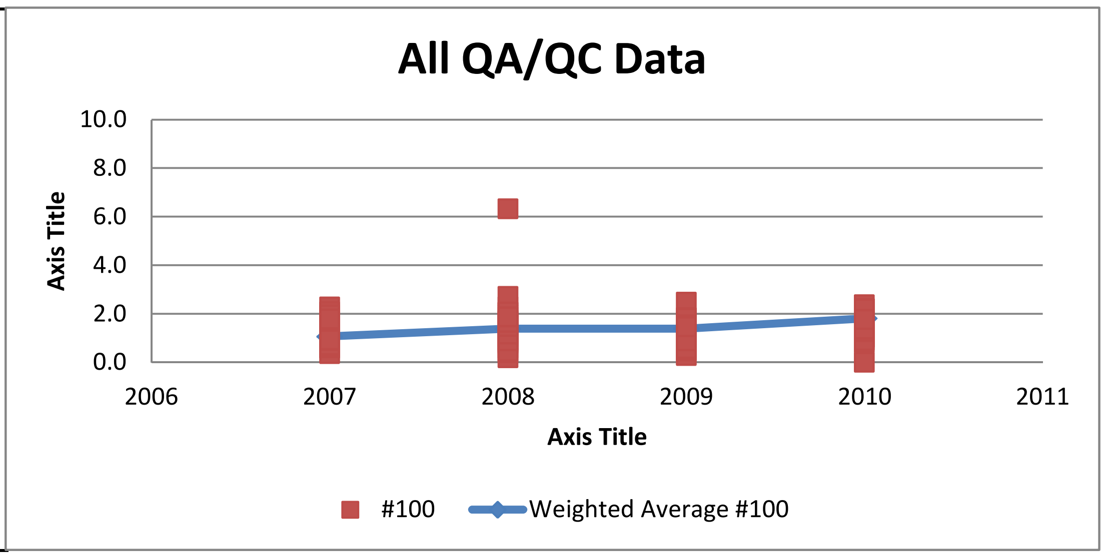
#200/Pbe- Percent passing the #200 sieve divided by the effective percent binder



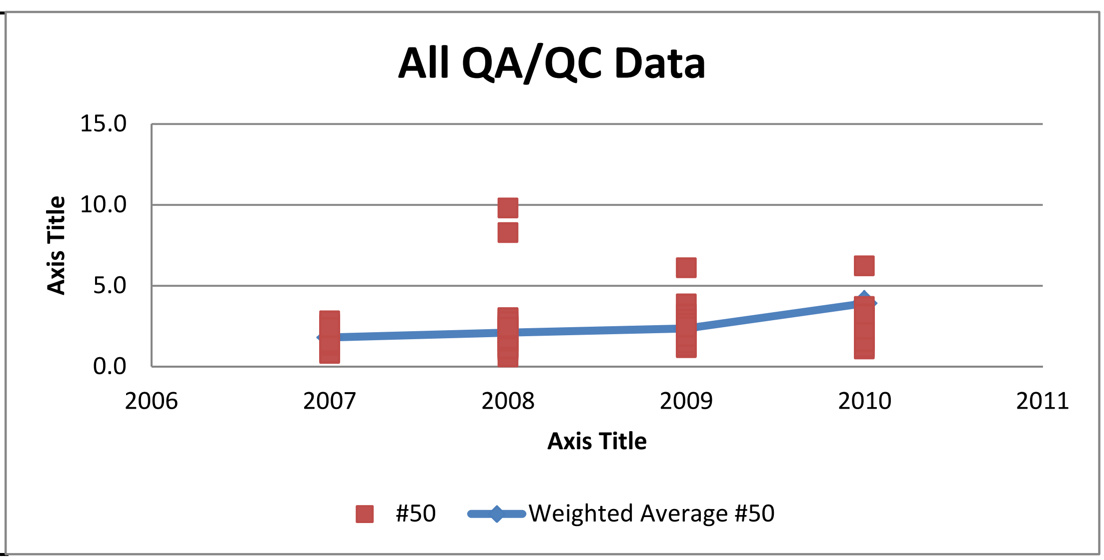
#200 - Percent Passing #200 Sieve



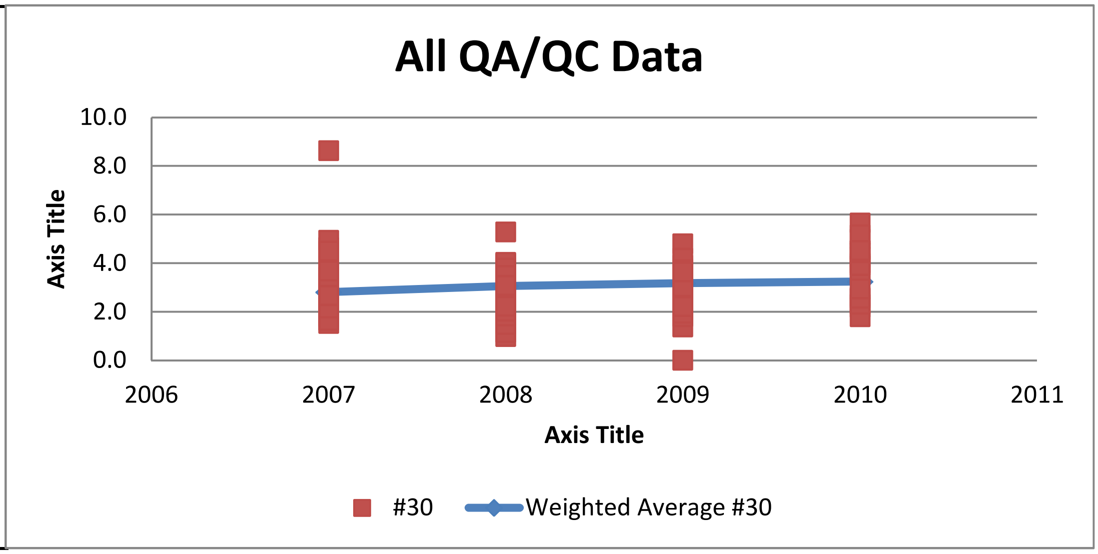
#100 - Percent Passing #100 Sieve



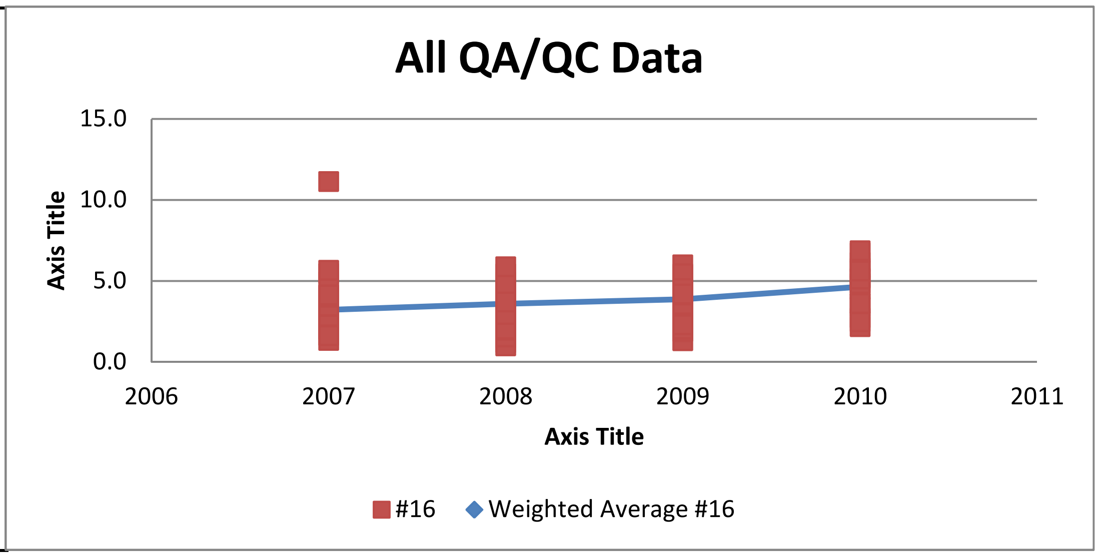
#50 - Percent Passing #50 Sieve



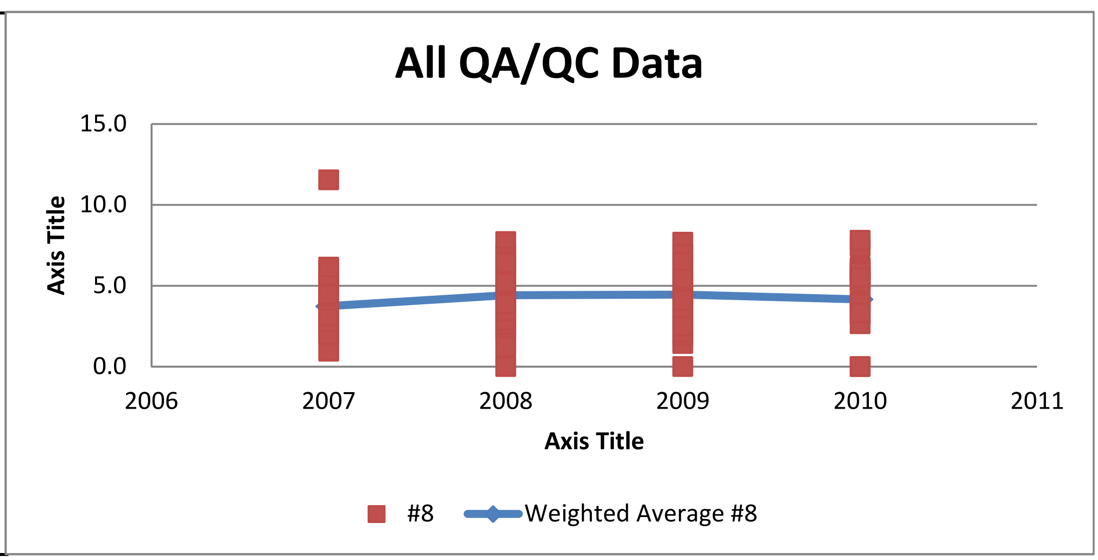
#30 - Percent Passing #30 Sieve



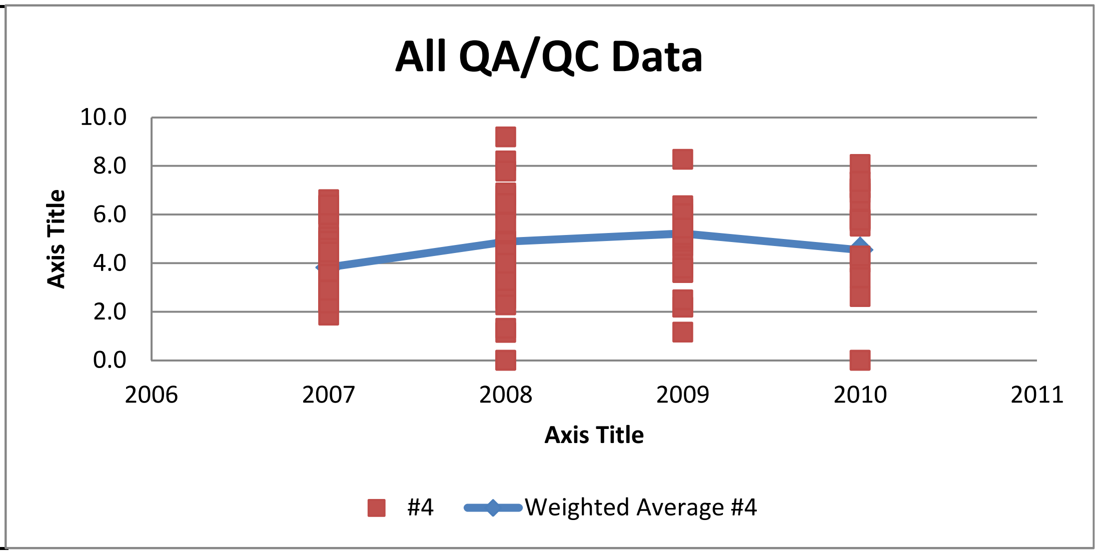
#16 - Percent Passing #16 Sieve



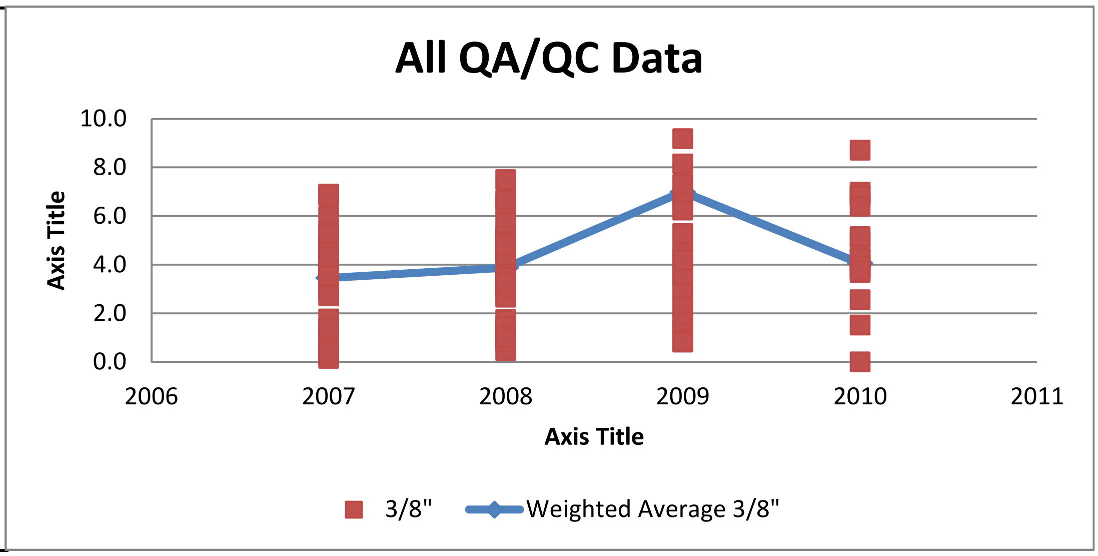
#8 - Percent Passing #8 Sieve



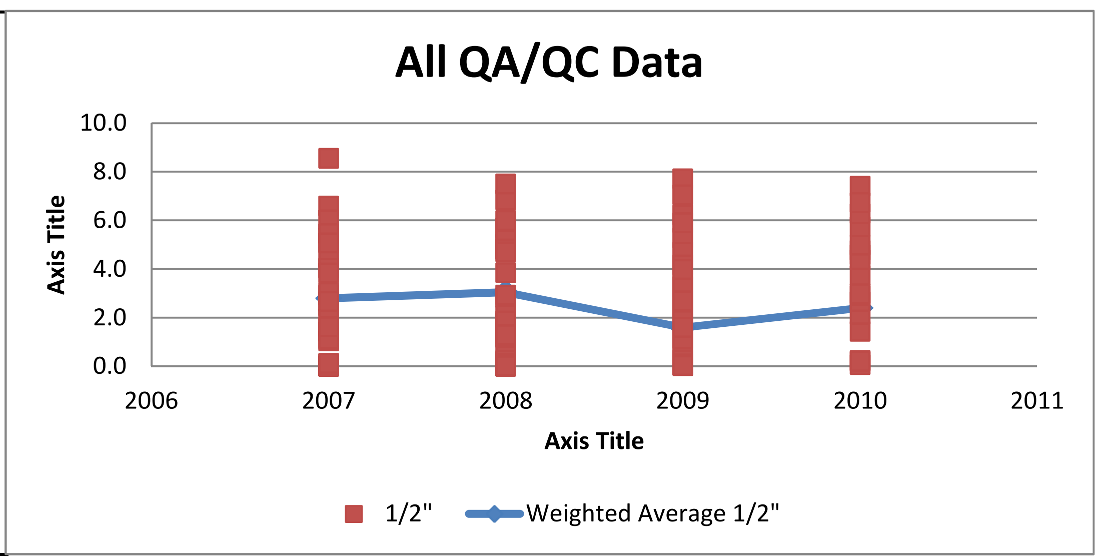
#4 - Percent Passing #4 Sieve



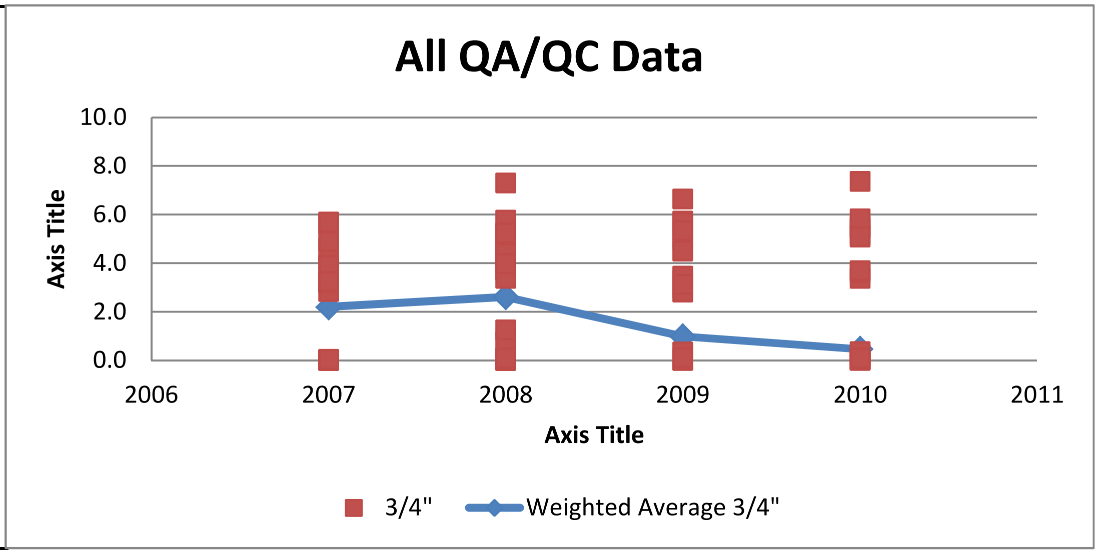
3/8" - Percent Passing 3/8" Sieve



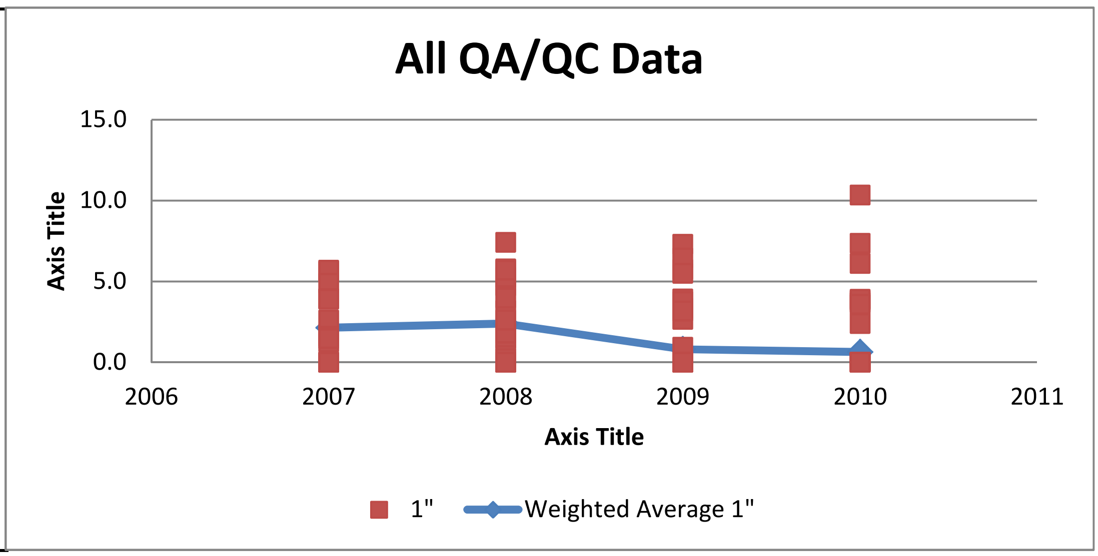
1/2" - Percent Passing 1/2" Sieve



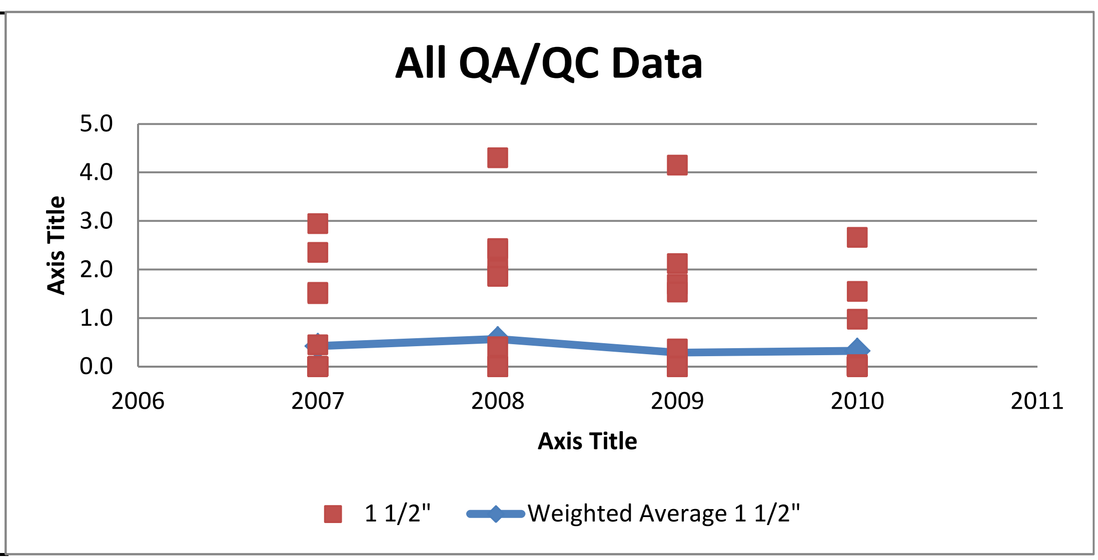
3/4" - Percent Passing 3/4" Sieve



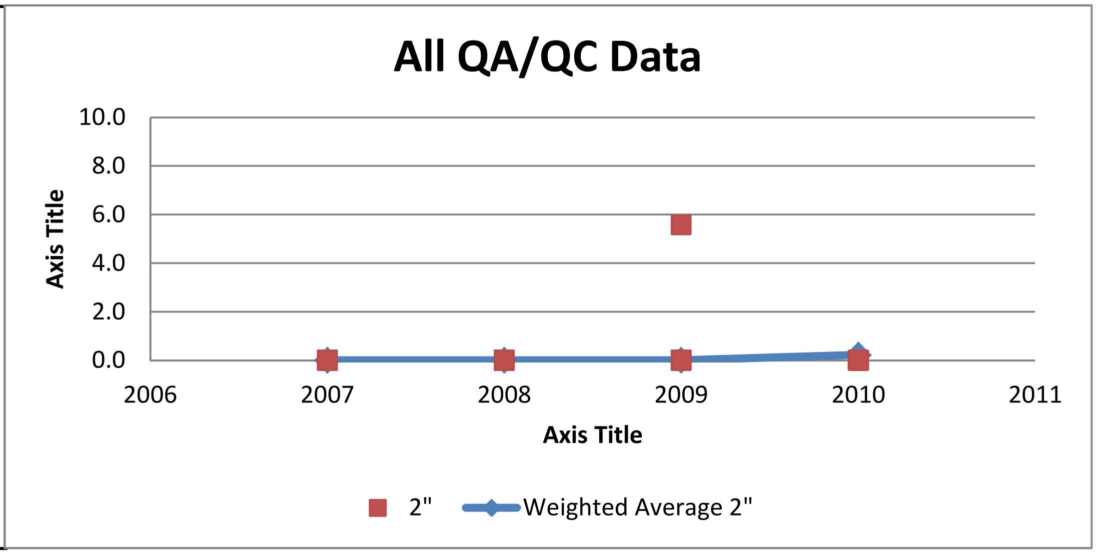
1" - Percent Passing 1" Sieve



1 1/2" - Percent Passing 1 1/2" Sieve



2" - Percent Passing 2" Sieve



Appendix C

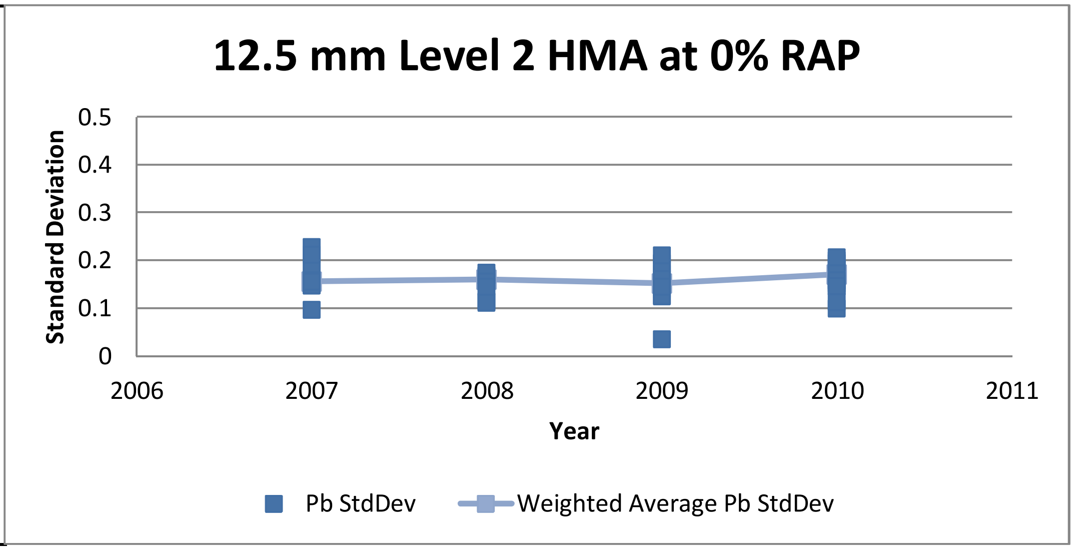
12.5 mm

Level 2

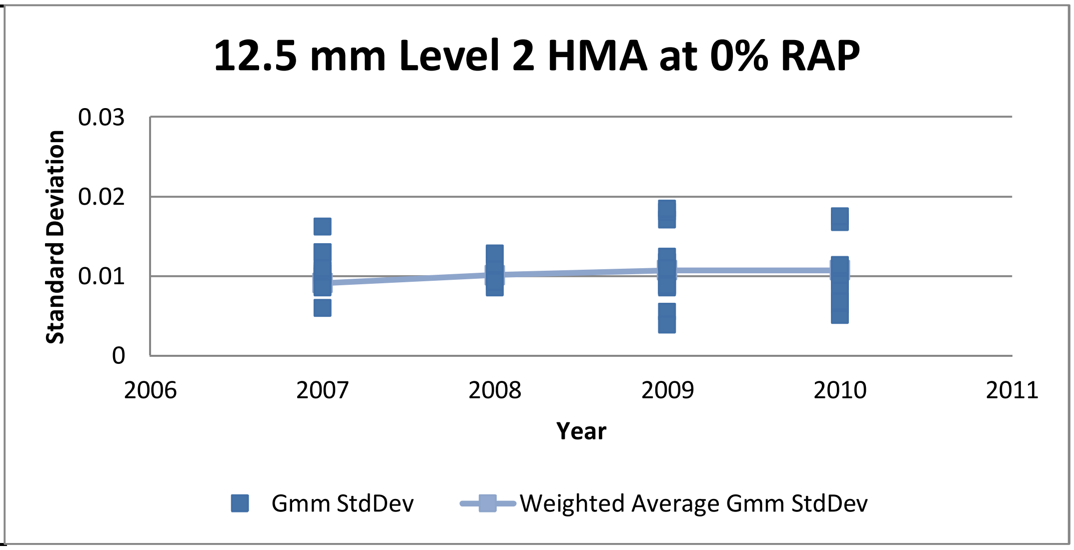
0% RAP

Each datapoint within a year is a different vendor

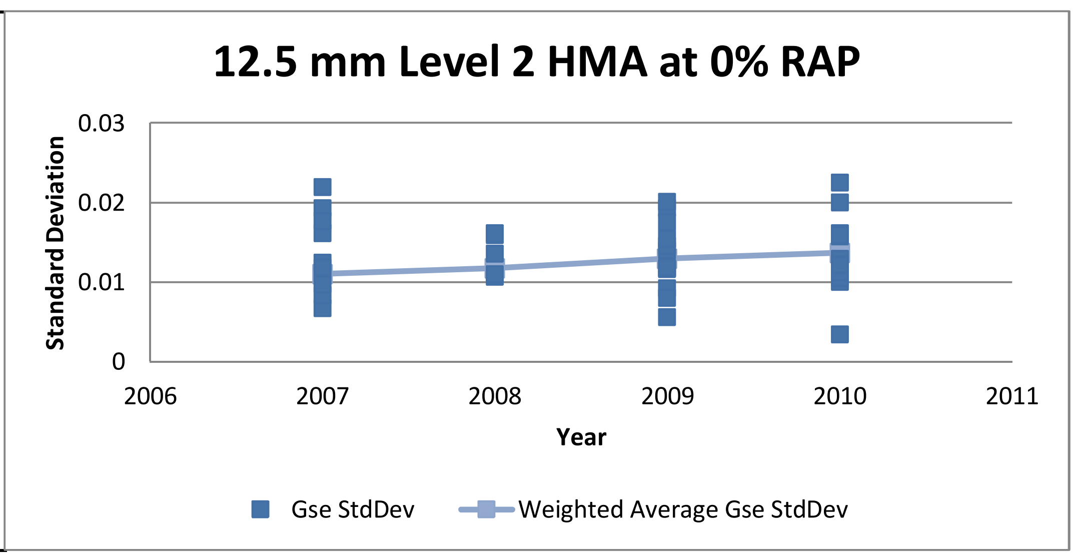
Pb- Percent Binder



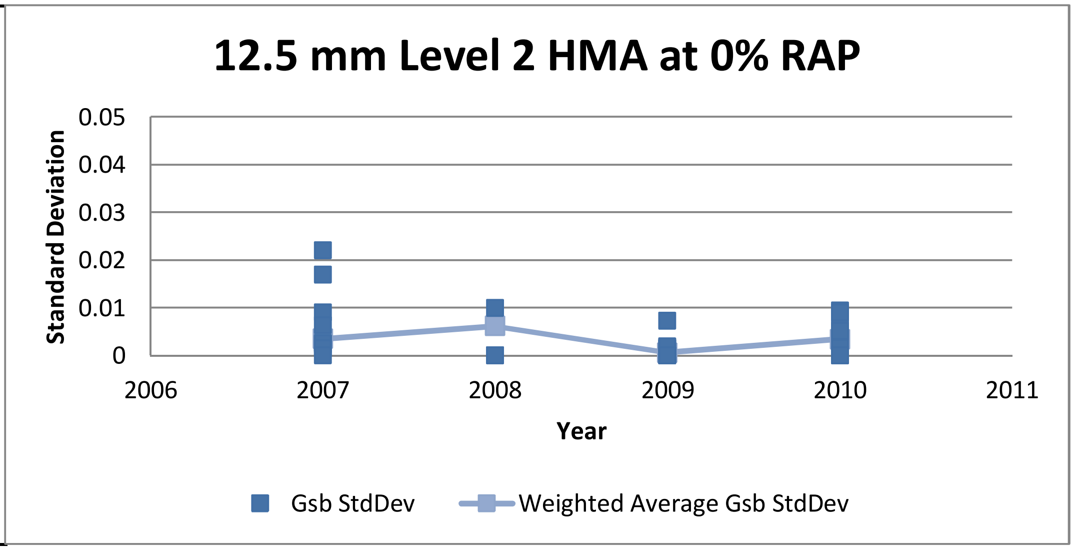
Gmm- Theoretical Maximum Specific Gravity (AASHTO T-209)



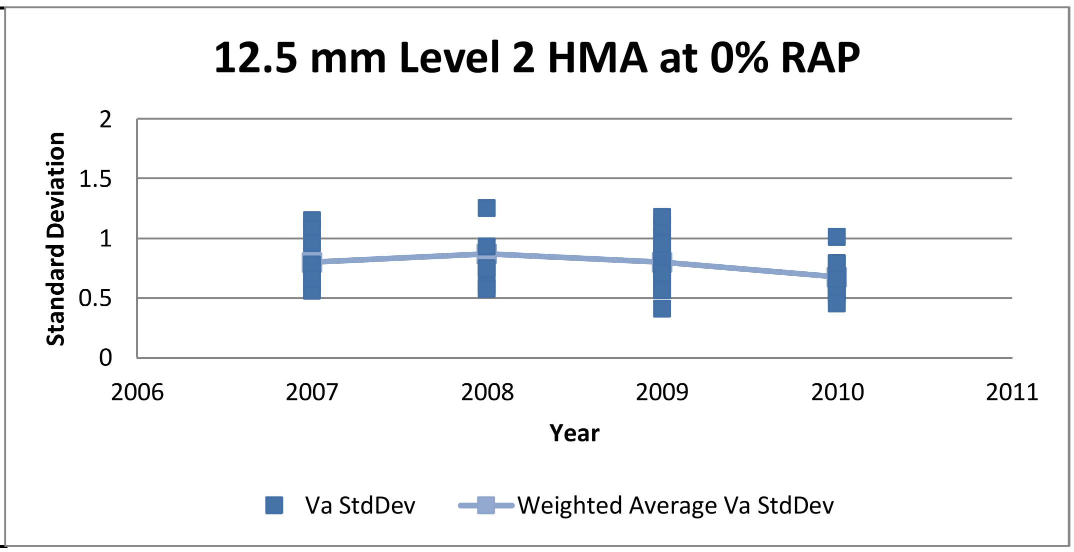
Gse- Effective Specific Gravity



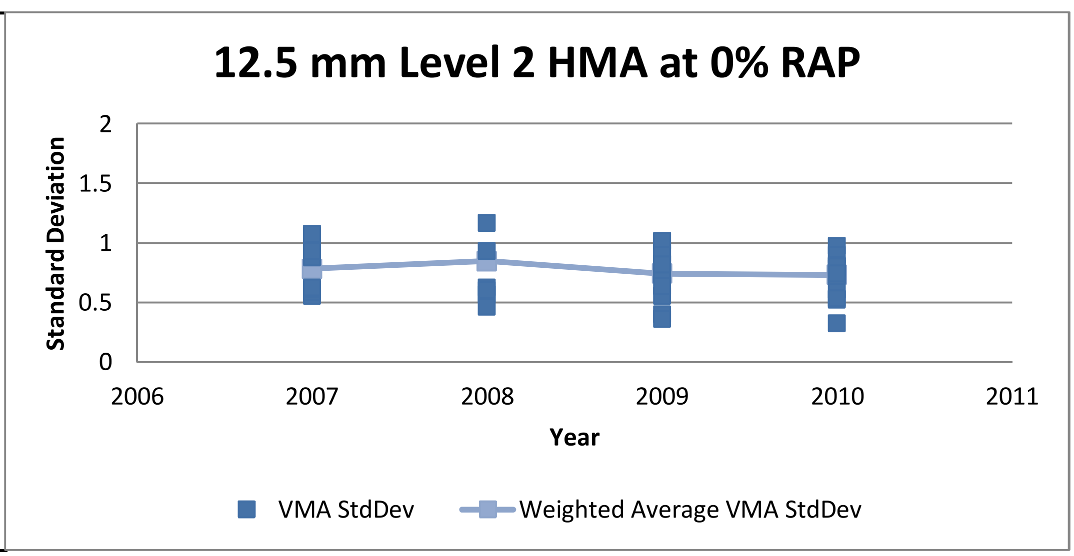
Gsb- Bulk Specific Gravity of the Blended Aggregate



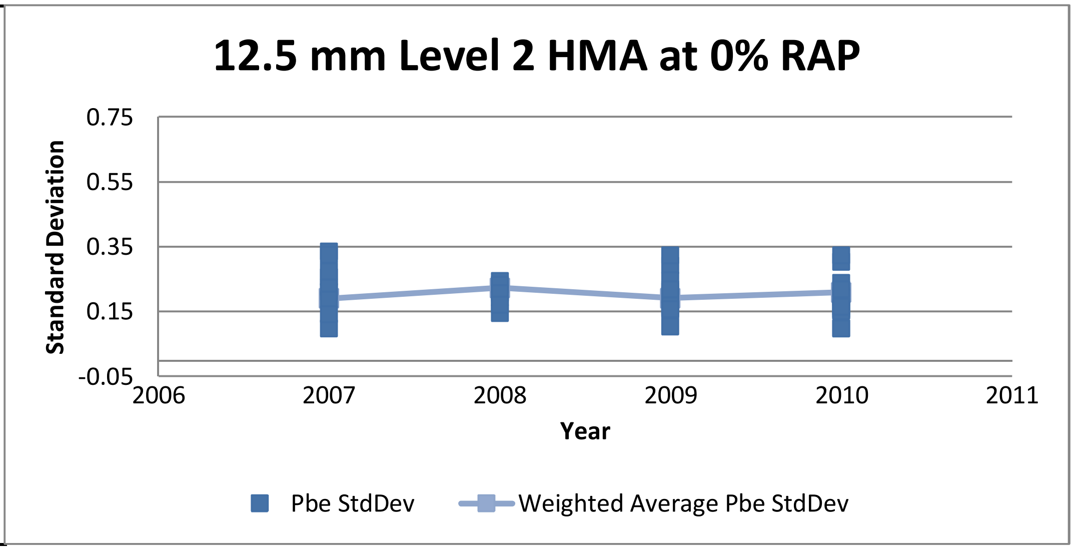
Va- Percent Air Voids



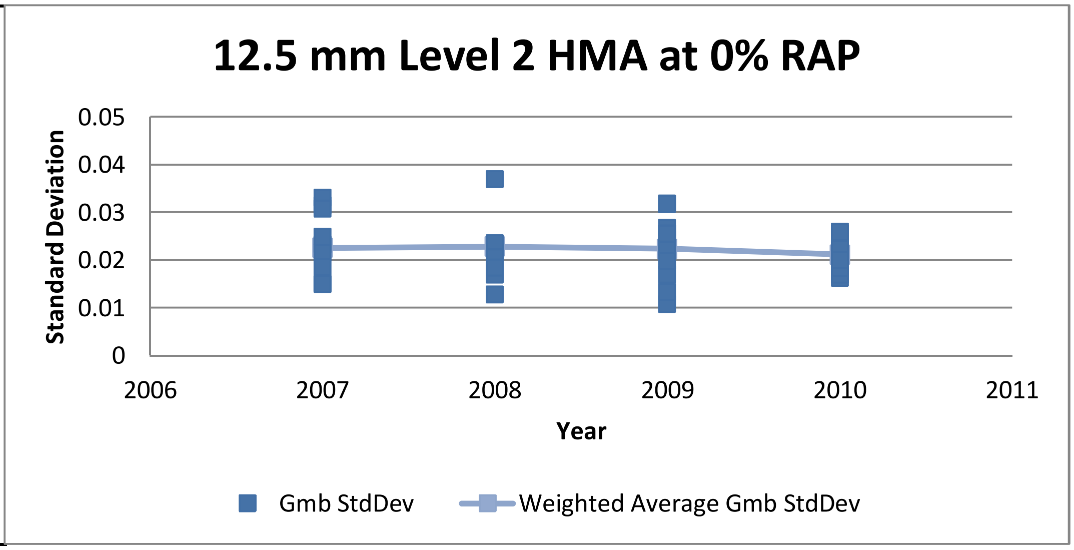
VMA- Voids in the Mineral Aggregate



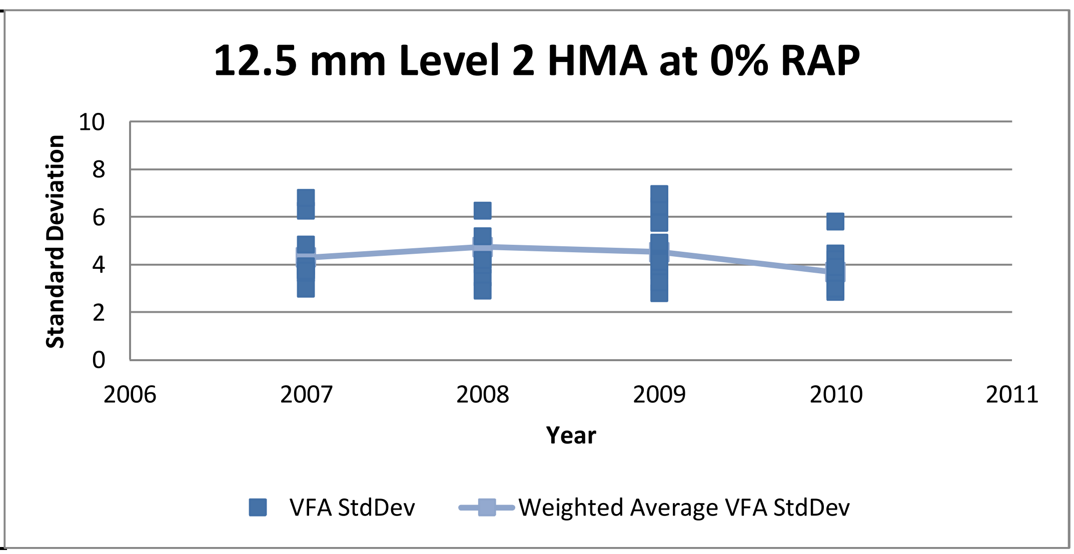
Pbe- Effective Percent Binder



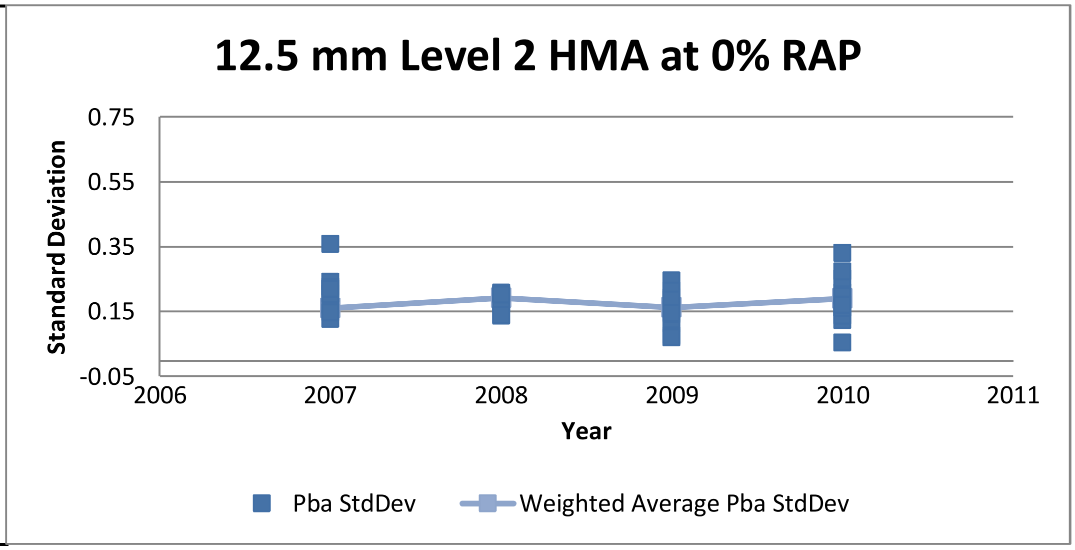
Gmb- Bulk Specific Gravity of the Mix (AASHTO T-166)



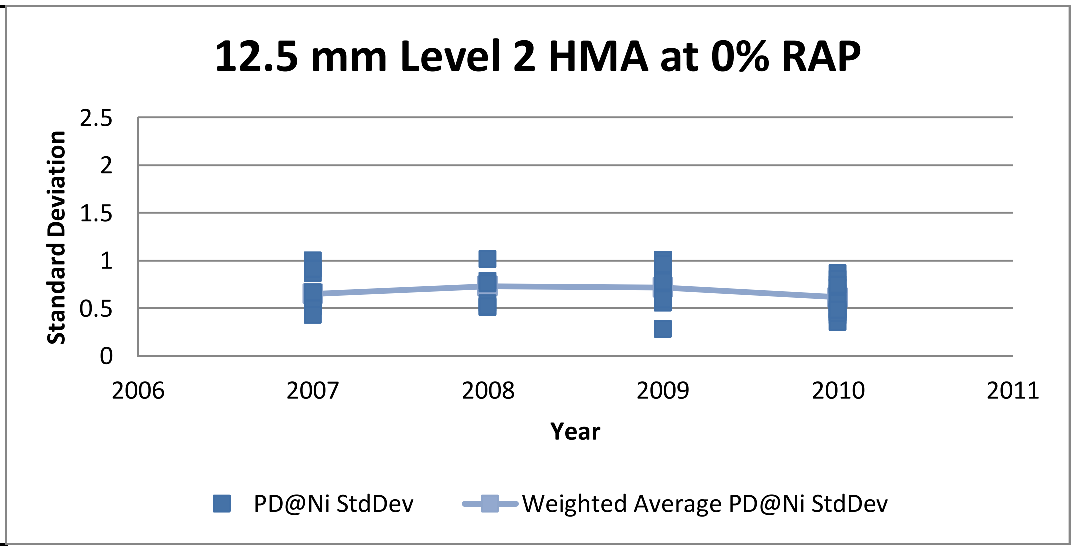
VFA- Voids Filled with Asphalt



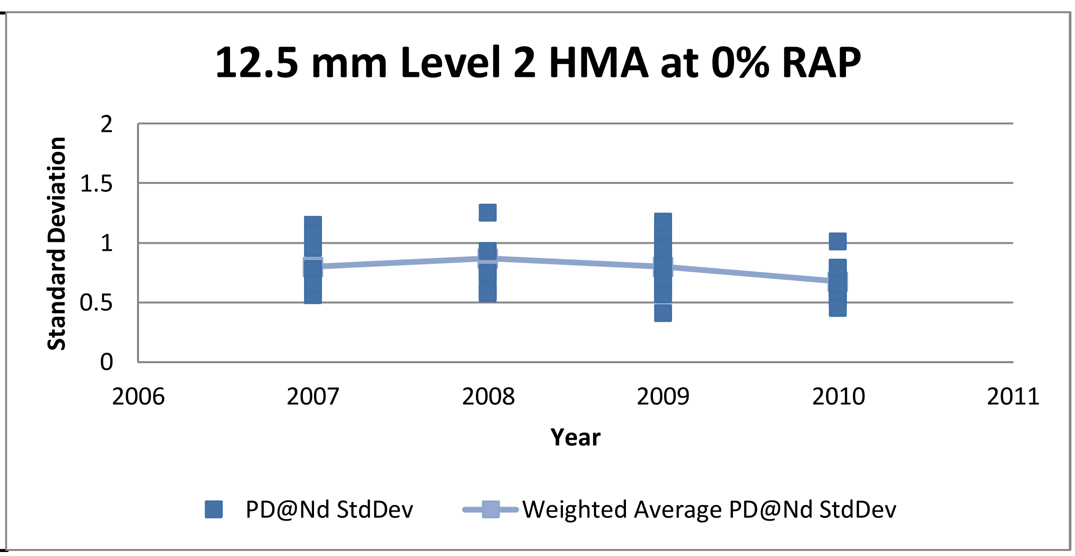
Pba- Percent Absorbed Asphalt



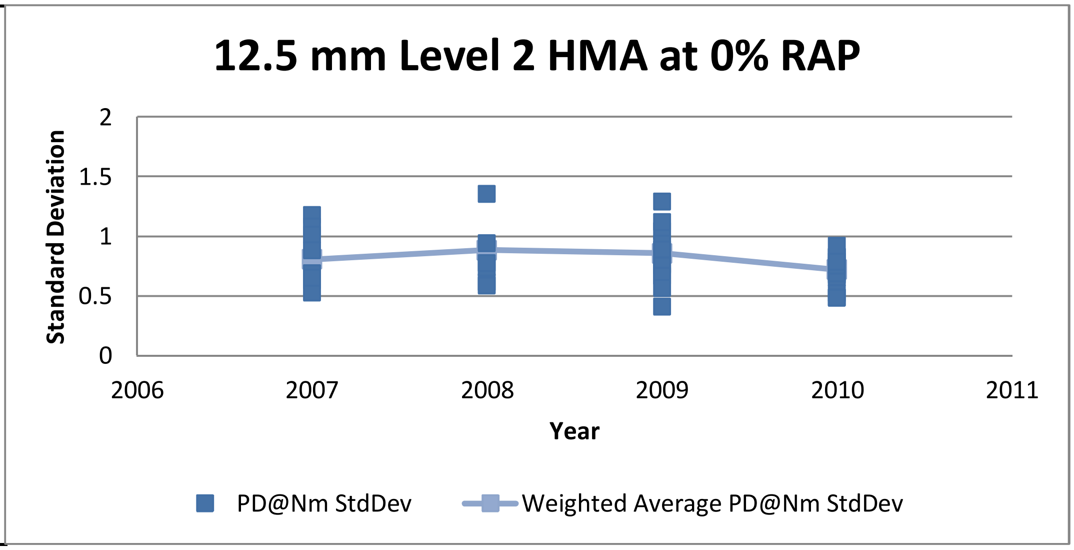
PD@Ni- Percent compaction at the initial number of gyrations



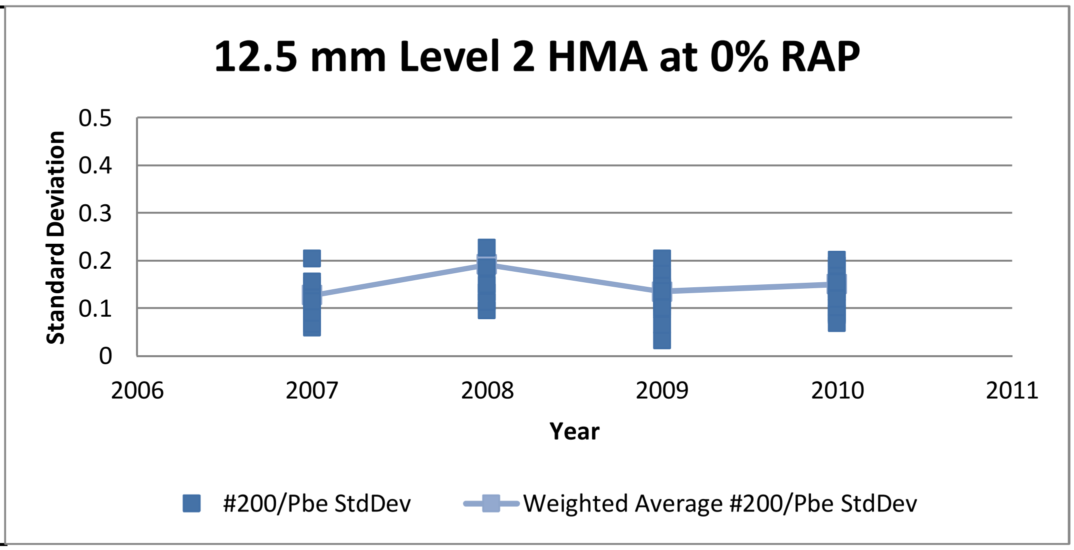
PD@Nd- Percent compaction at the design number of gyrations



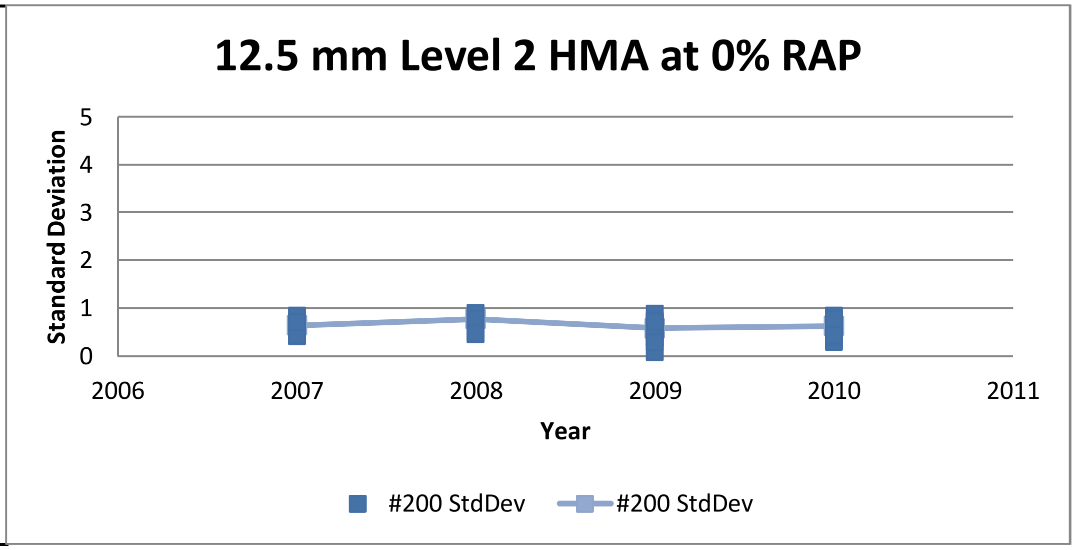
PD@Nm- Percent compaction at the maximum number of gyrations



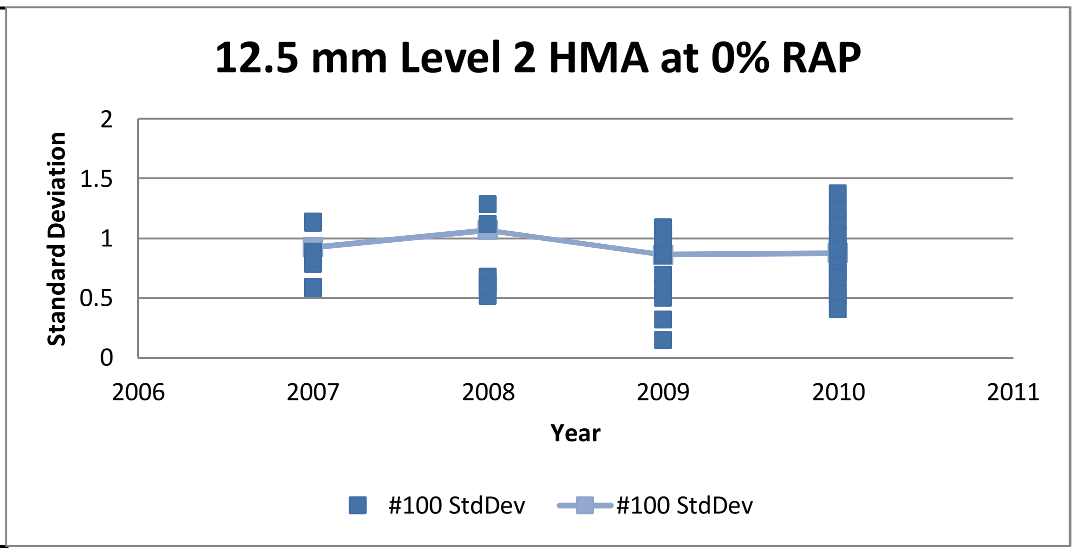
#200/Pbe- Percent passing the #200 sieve divided by the percent binder effective



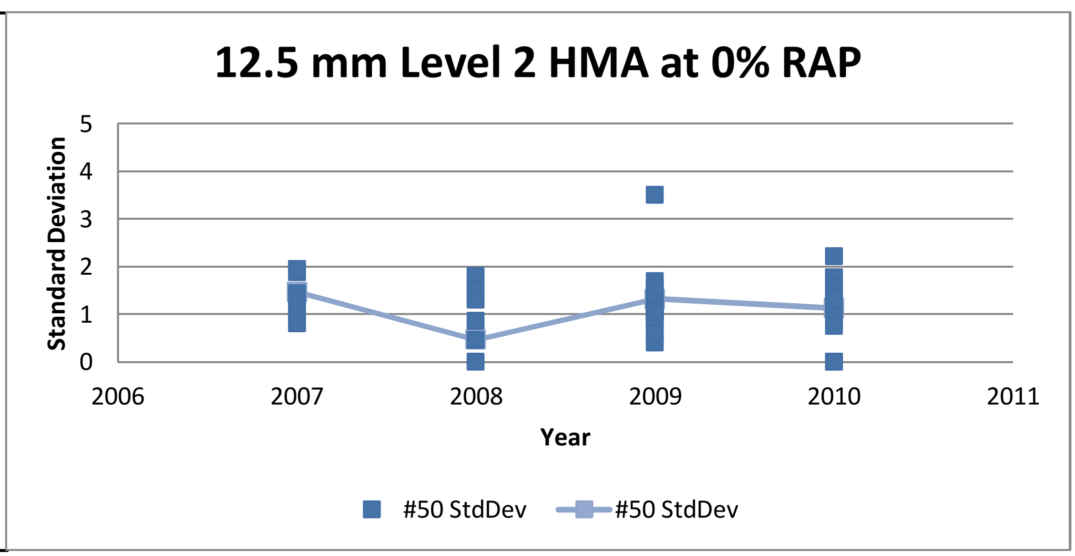
#200 - Percent Passing #200 Sieve



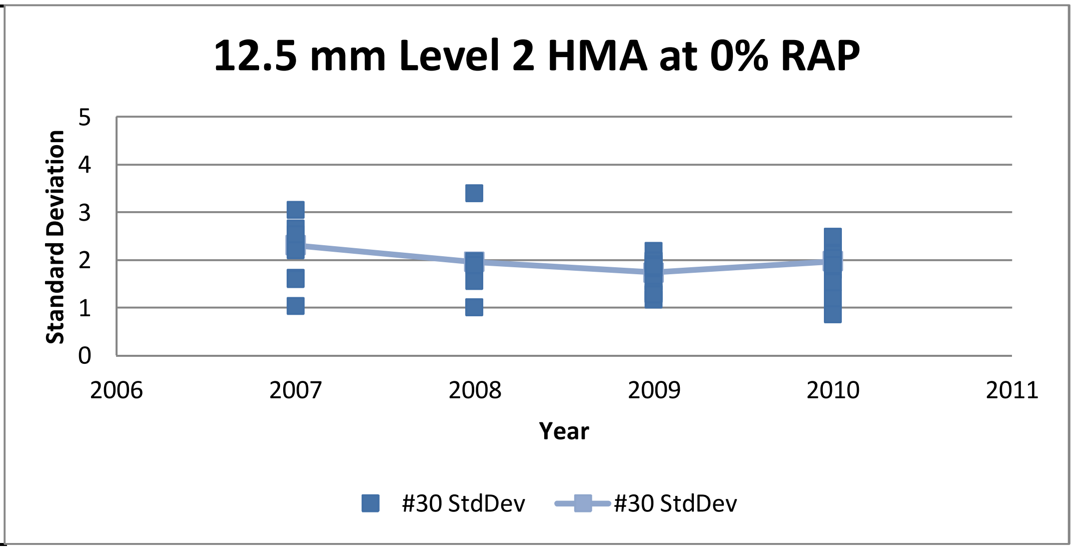
#100 - Percent Passing #100 Sieve



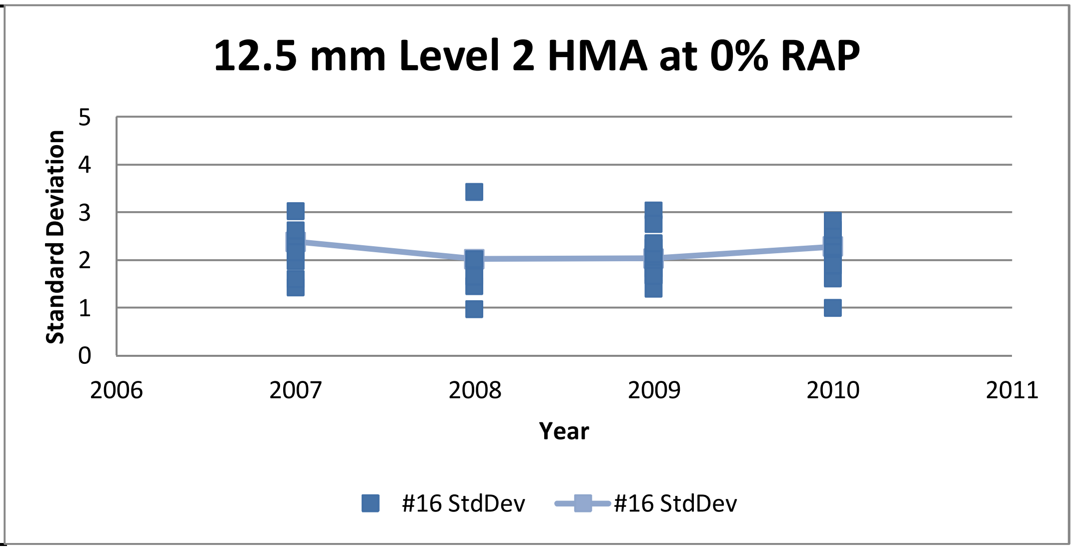
#50 - Percent Passing #50 Sieve



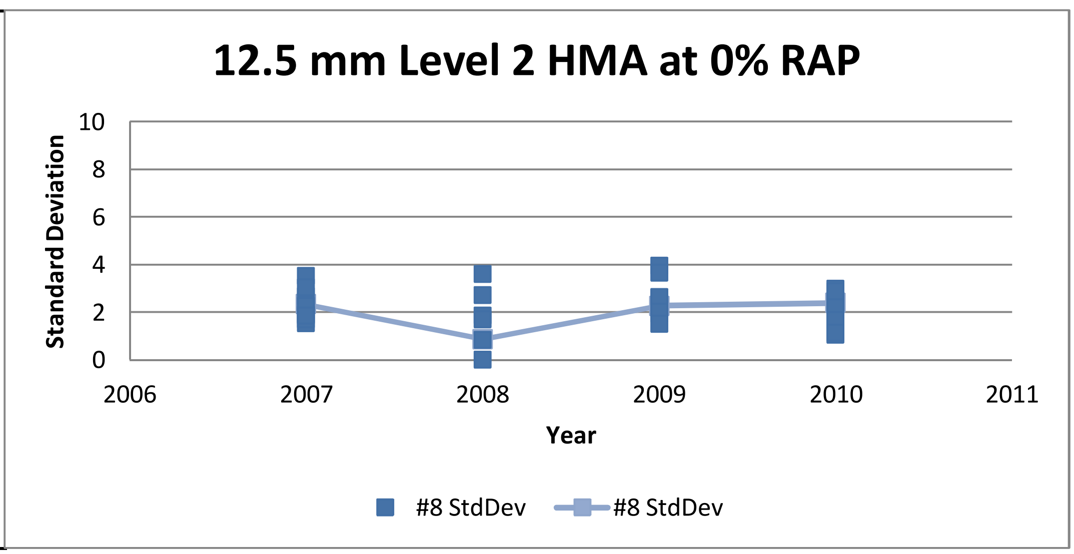
#30 - Percent Passing #30 Sieve



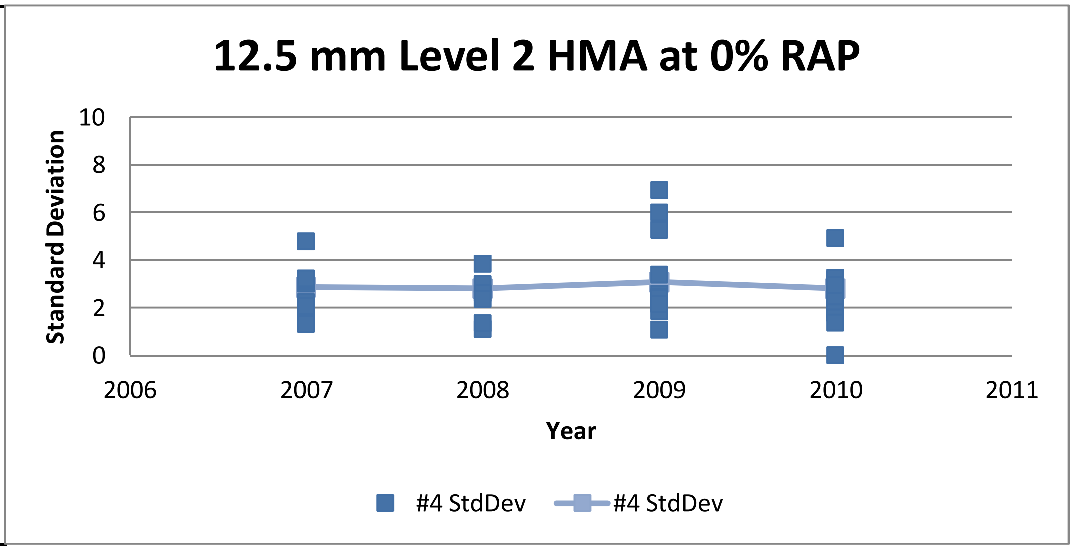
#16 - Percent Passing #16 Sieve



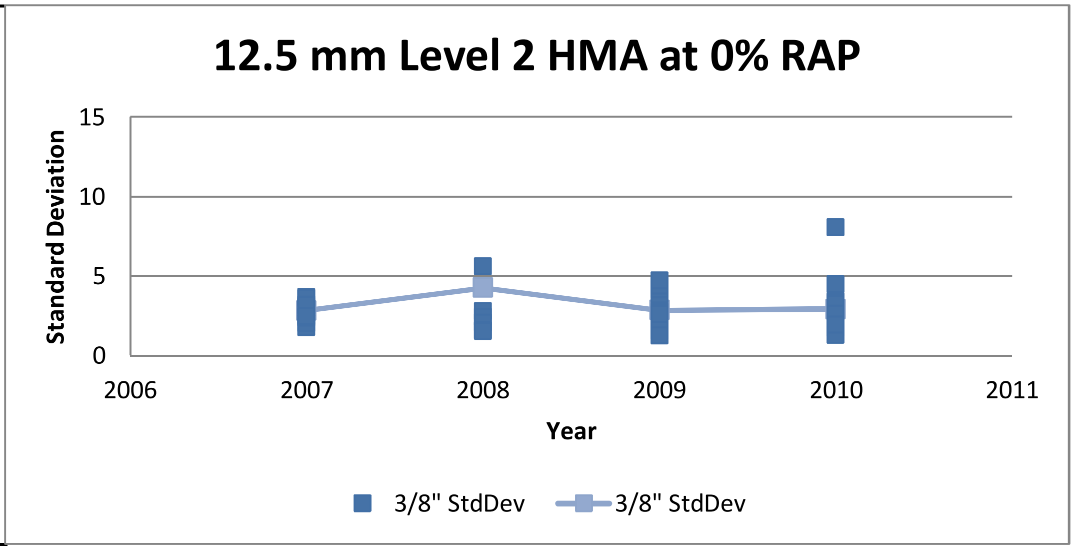
#8 - Percent Passing #8 Sieve



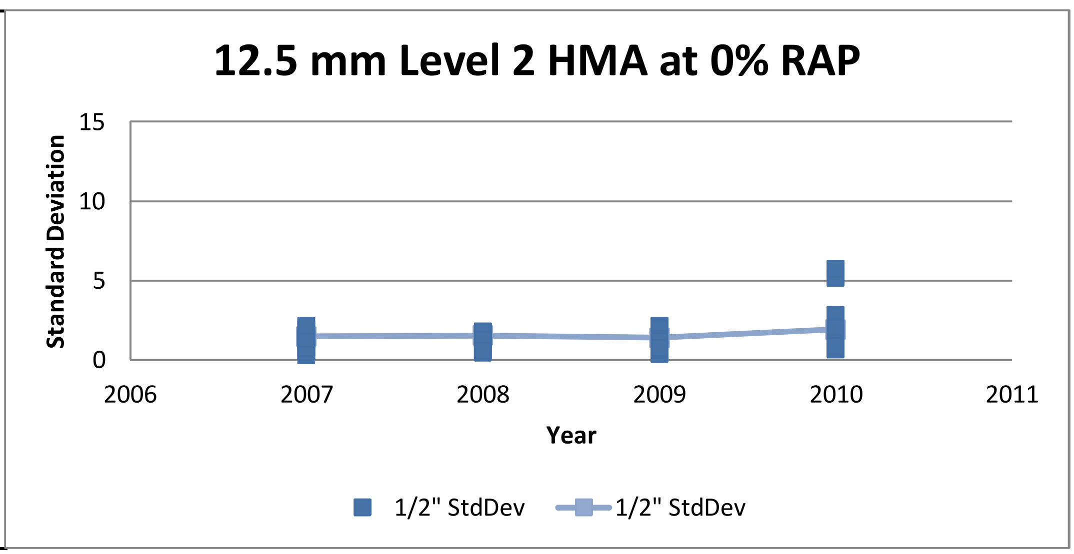
#4 - Percent Passing #4 Sieve



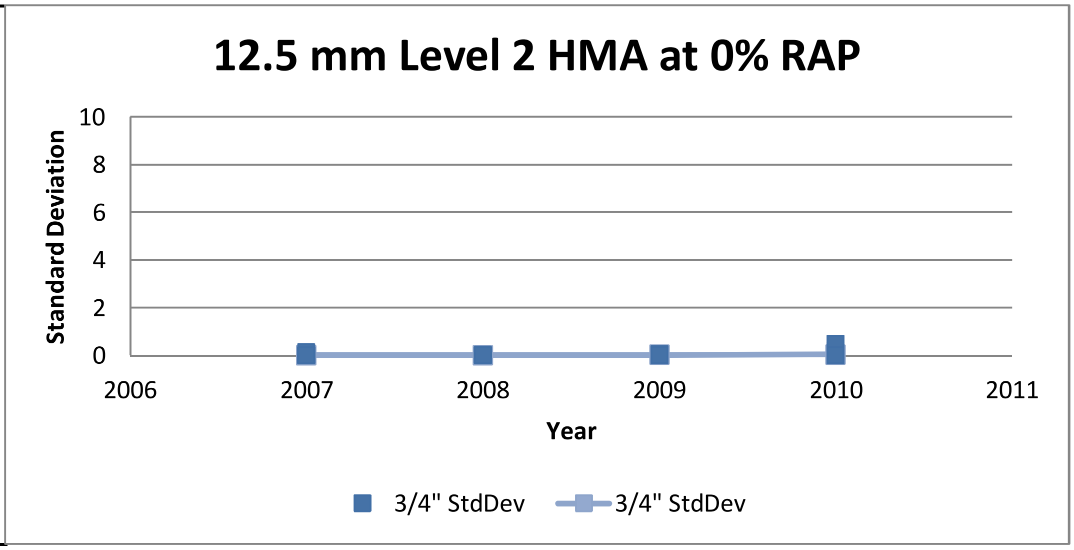
3/8" - Percent Passing 3/8" Sieve



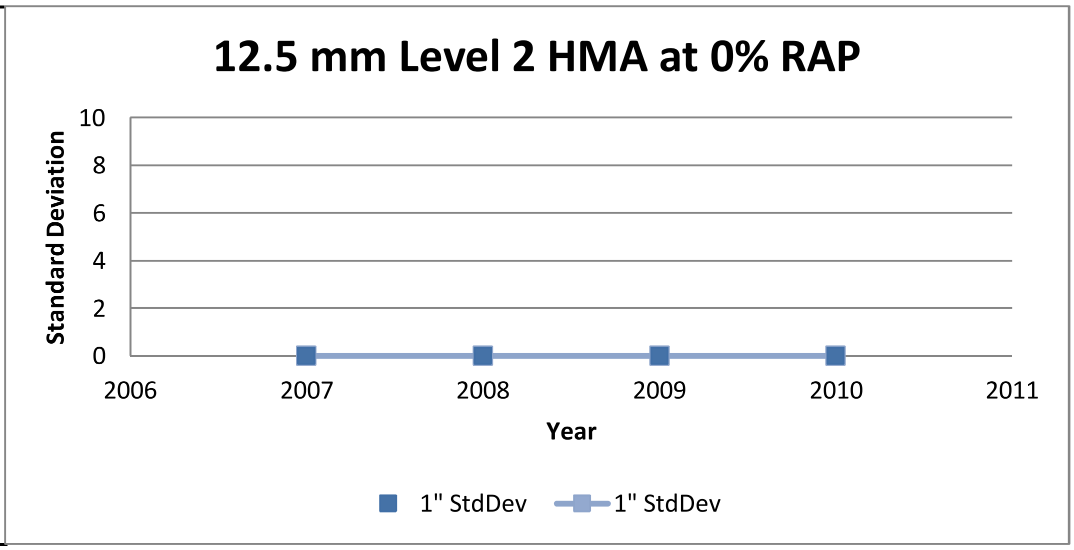
1/2" - Percent Passing 1/2" Sieve



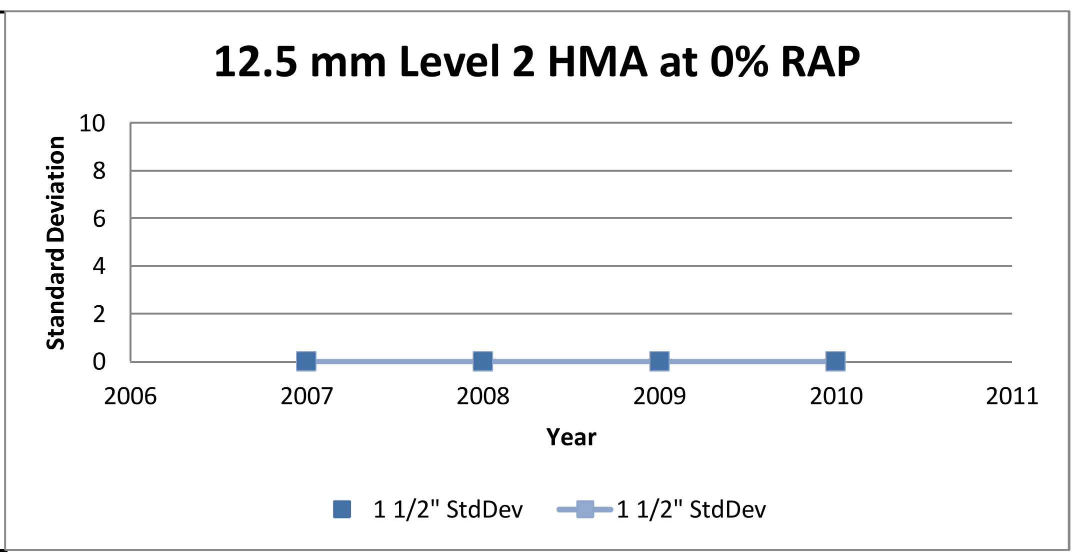
3/4" - Percent Passing 3/4" Sieve



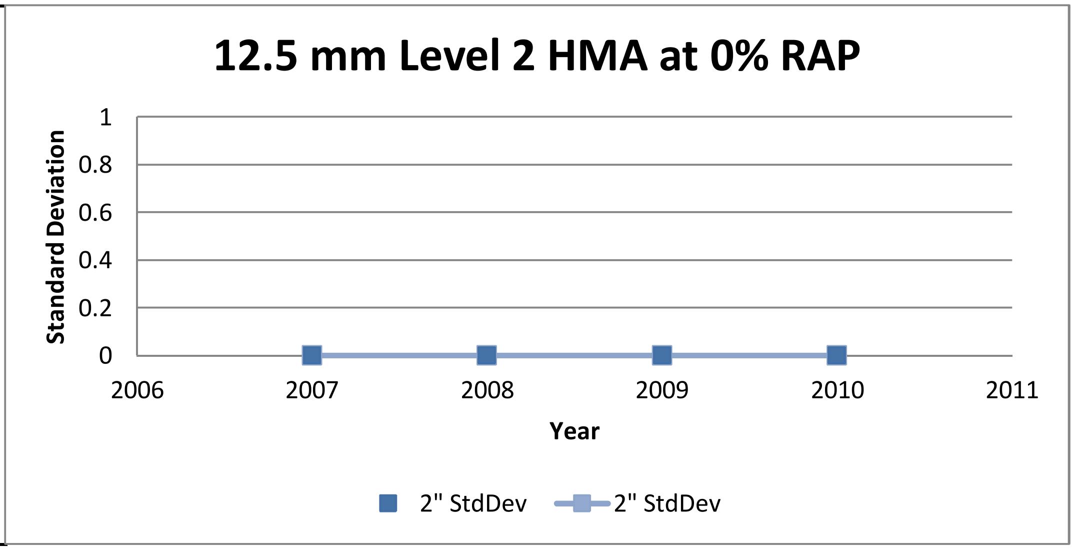
1" - Percent Passing 1" Sieve



1 1/2" - Percent Passing 1 1/2" Sieve



2" - Percent Passing 2" Sieve



Appendix D

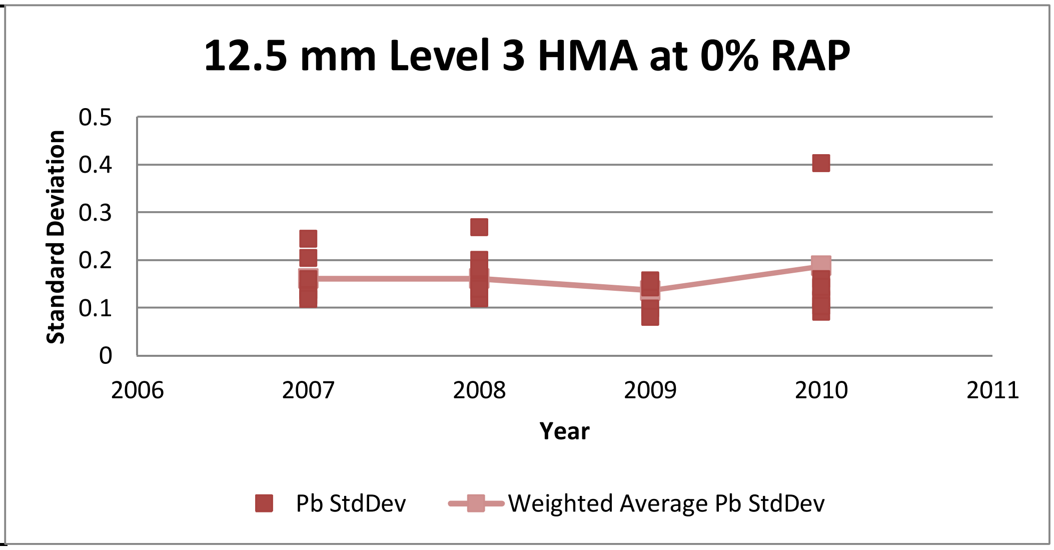
12.5 mm

Level 3

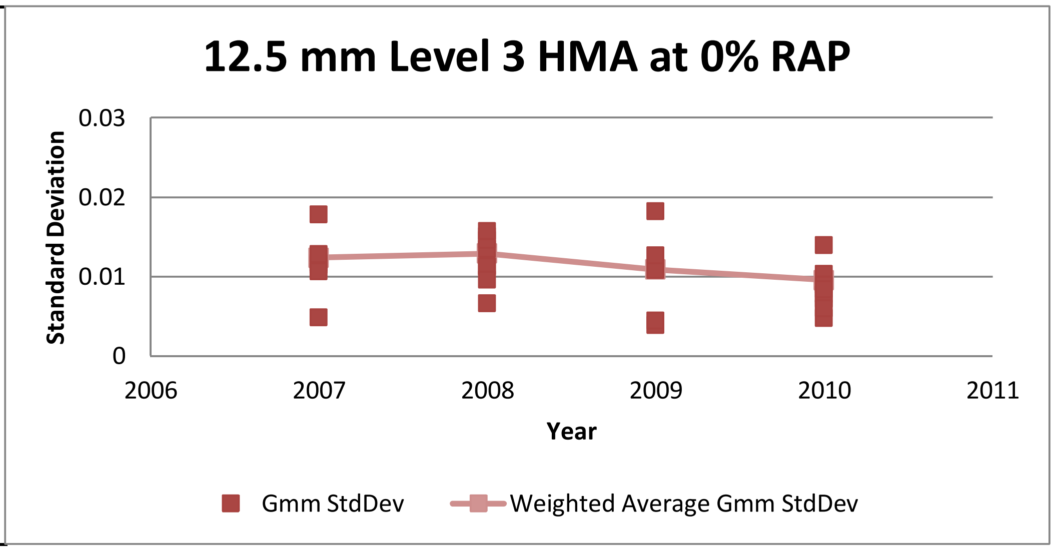
0% RAP

Each datapoint within a year is a different vendor

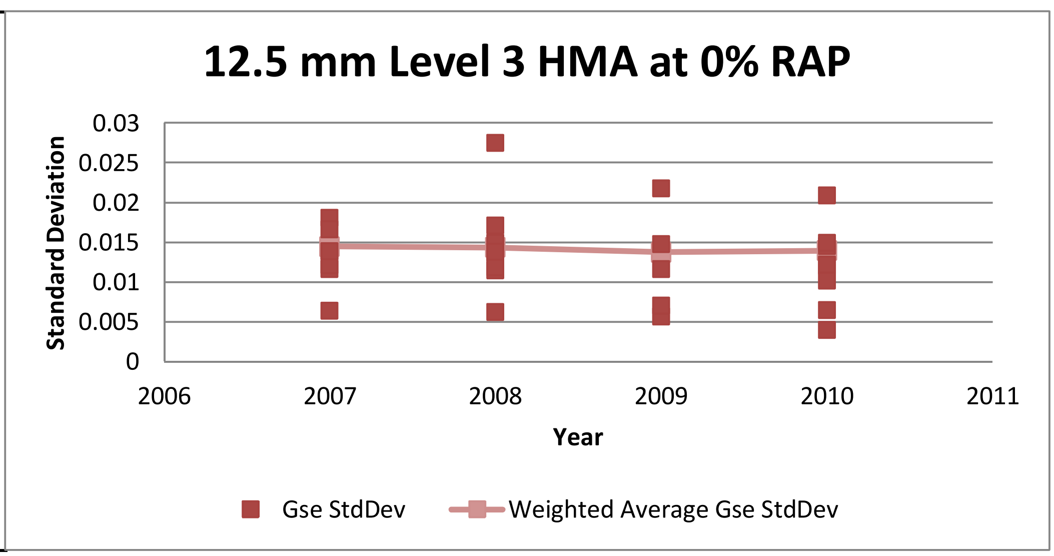
Pb- Percent Binder



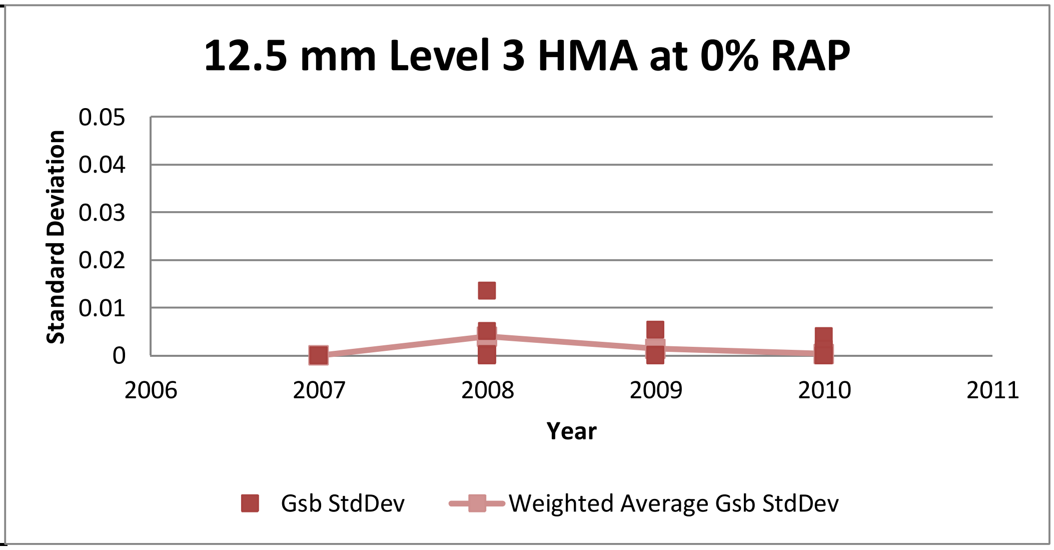
Gmm- Theoretical Maximum Specific Gravity (AASHTO T-209)



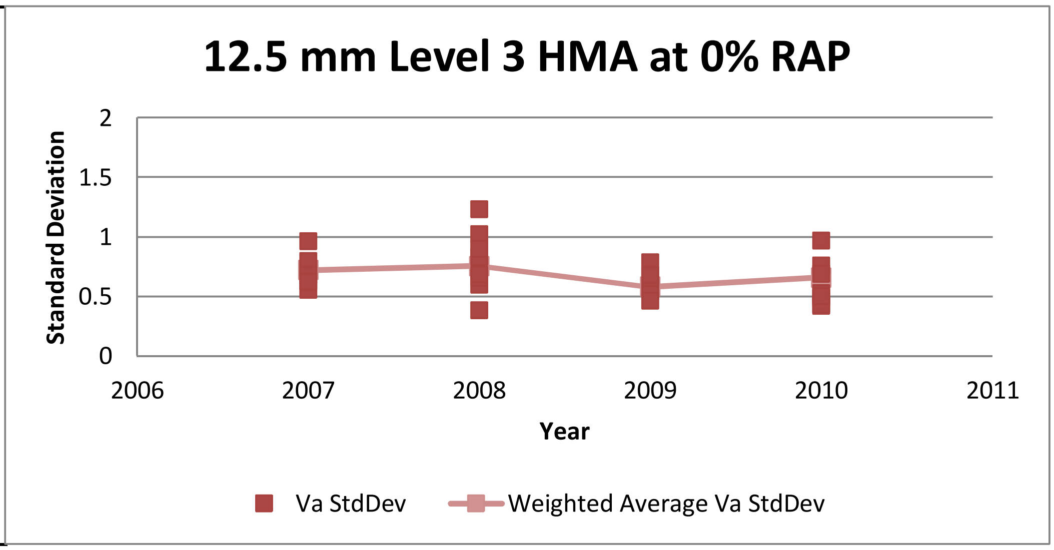
Gse- Effective Specific Gravity



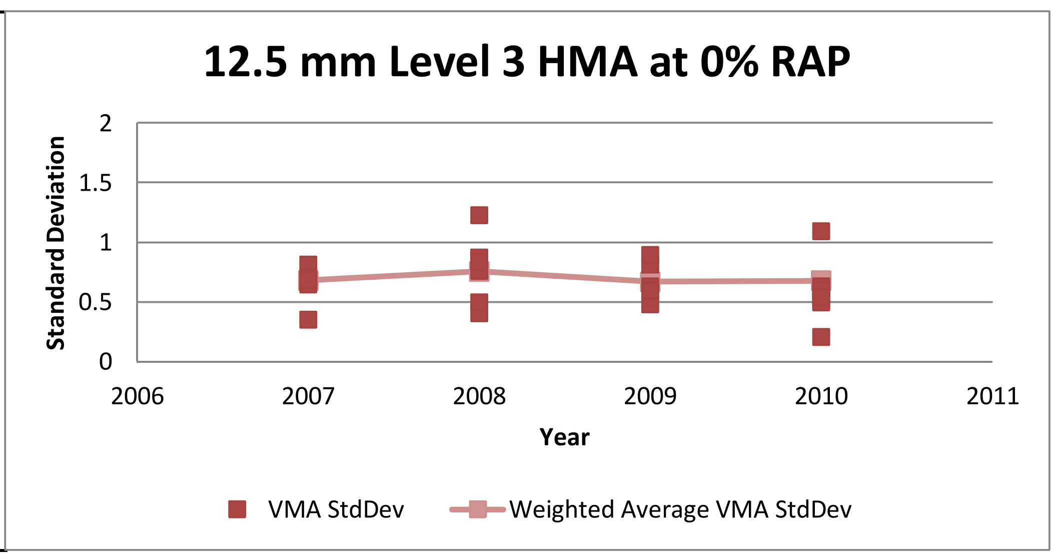
Gsb- Bulk Specific Gravity of the Blended Aggregate



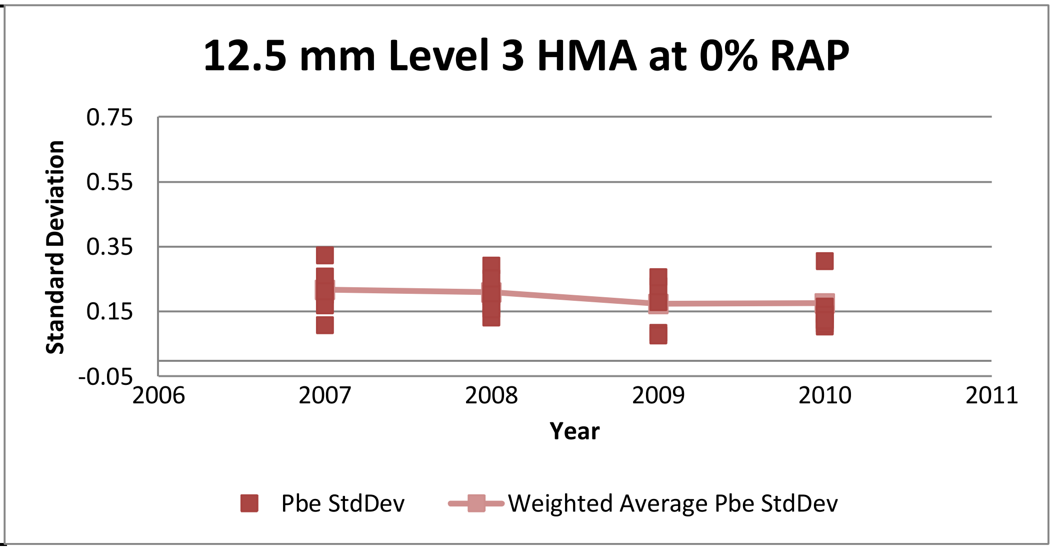
Va- Percent Air Voids



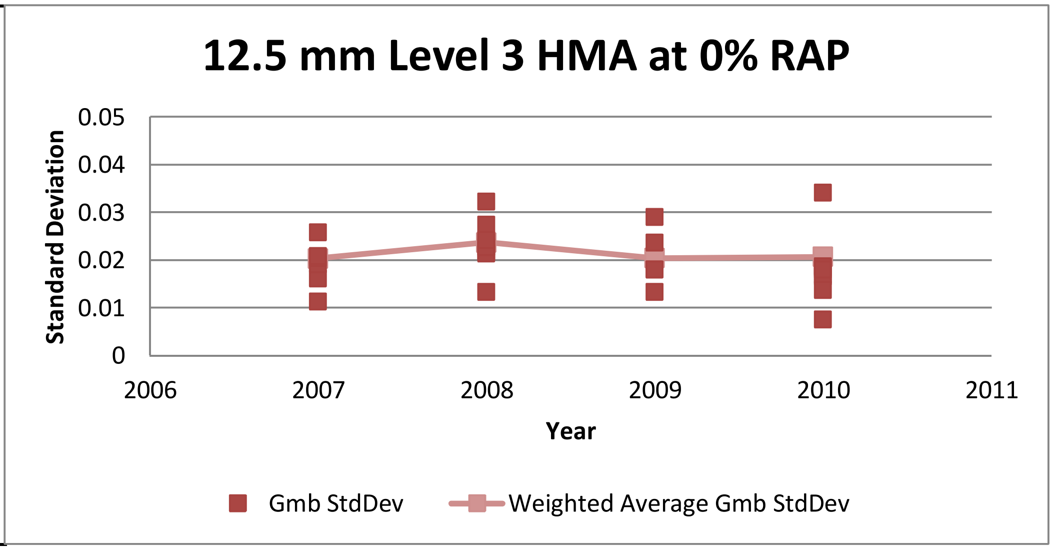
VMA- Voids in the Mineral Aggregate



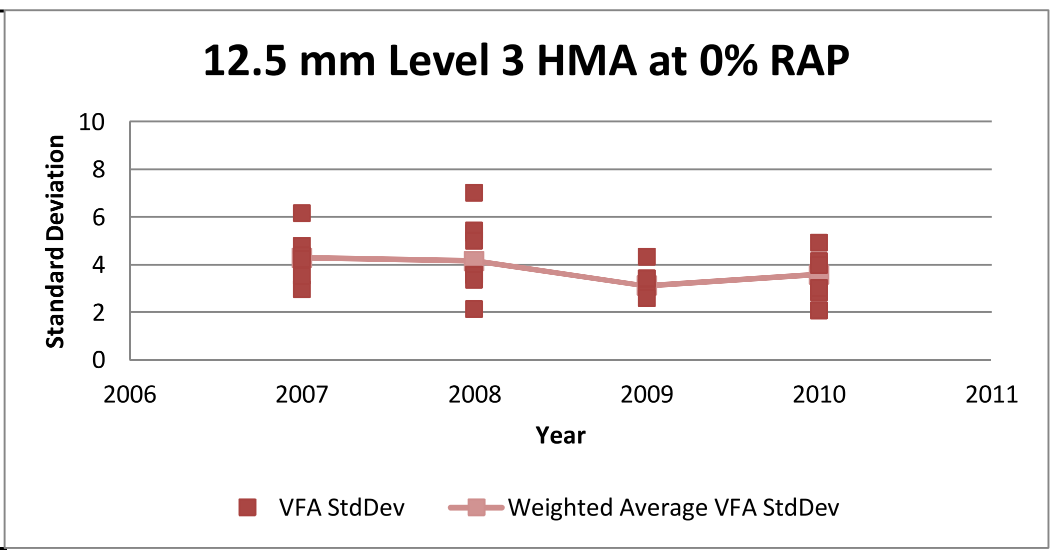
Pbe- Effective Percent Binder



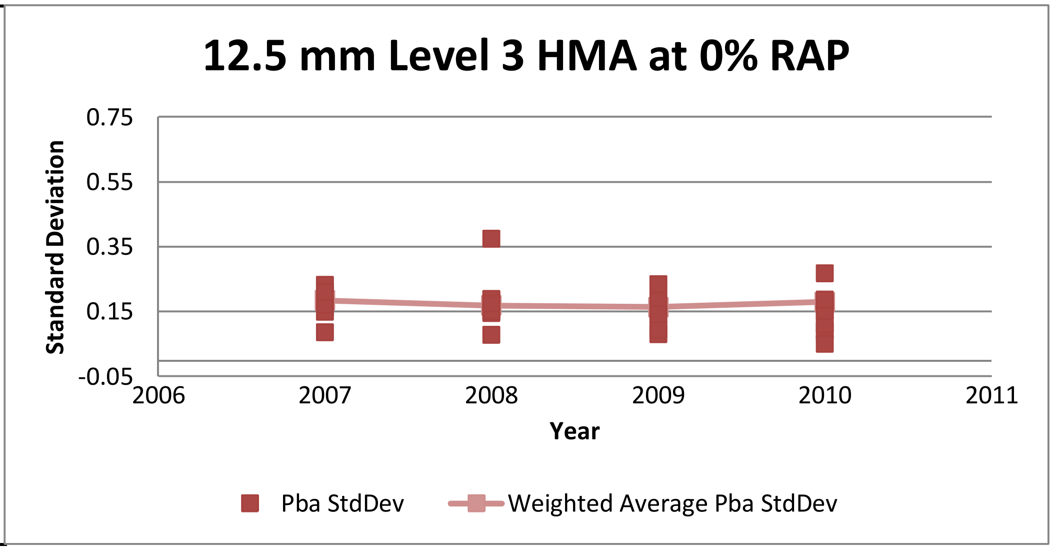
Gmb- Bulk Specific Gravity of the Mix (AASHTO T-166)



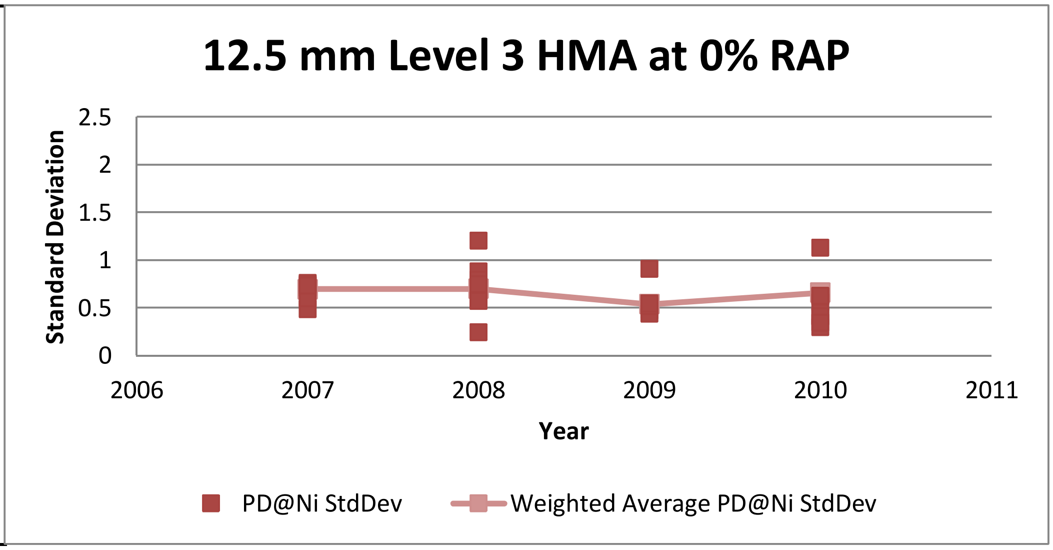
VFA- Voids Filled with Asphalt



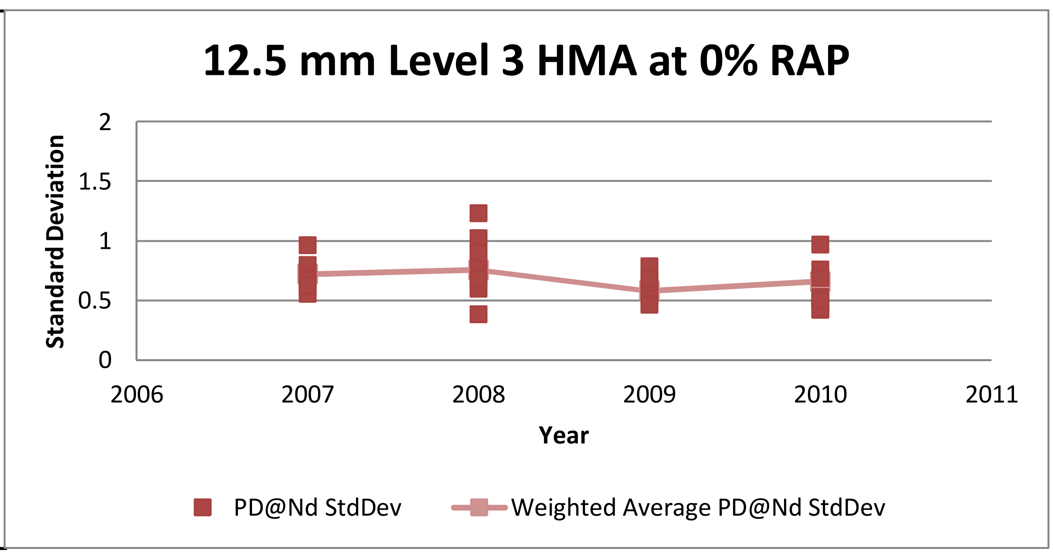
Pba- Percent Absorbed Asphalt



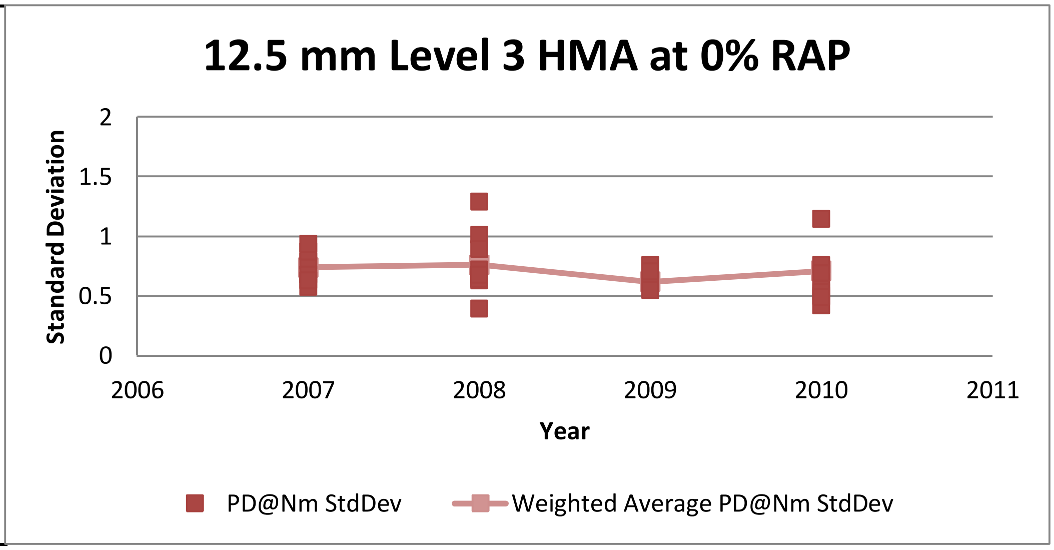
PD@Ni- Percent compaction at the initial number of gyrations



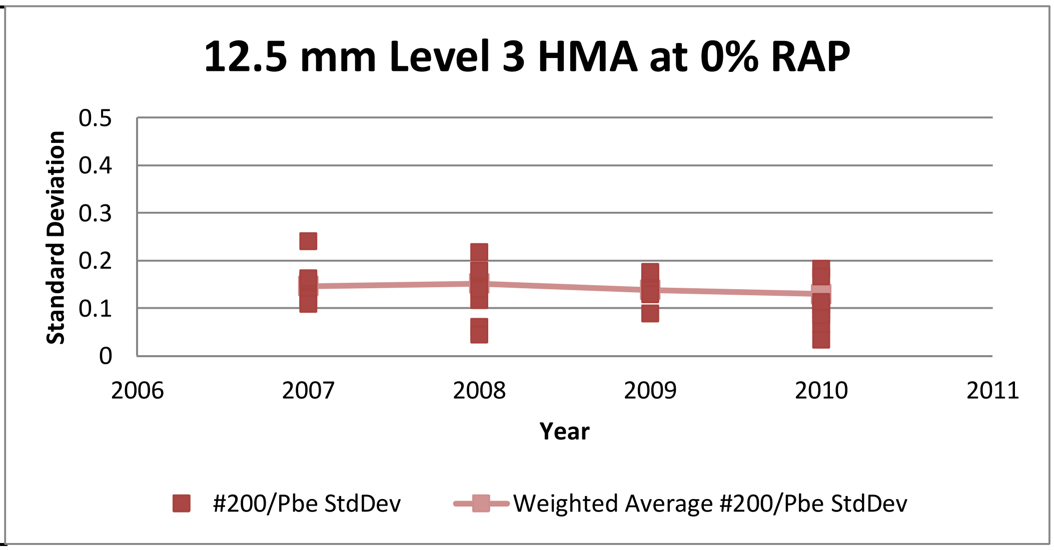
PD@Nd- Percent compaction at the design number of gyrations



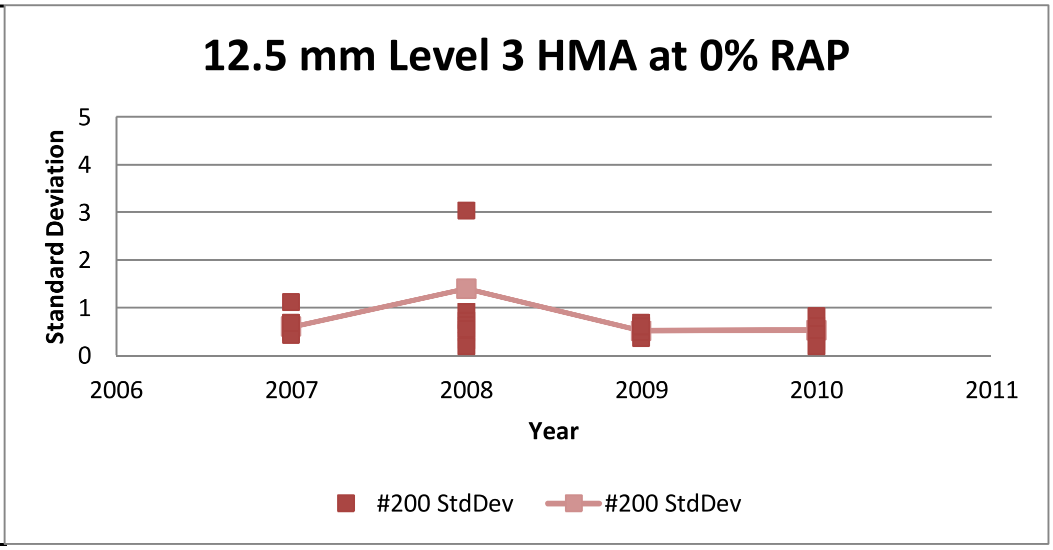
PD@Nm- Percent compaction at the maximum number of gyrations



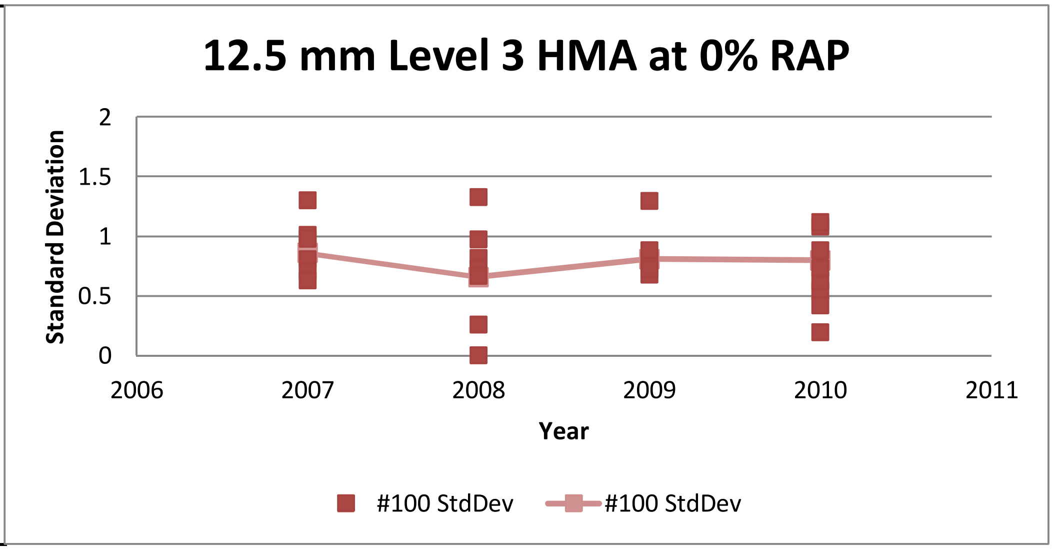
#200/Pbe- Percent passing the #200 sieve divided by the percent binder effective



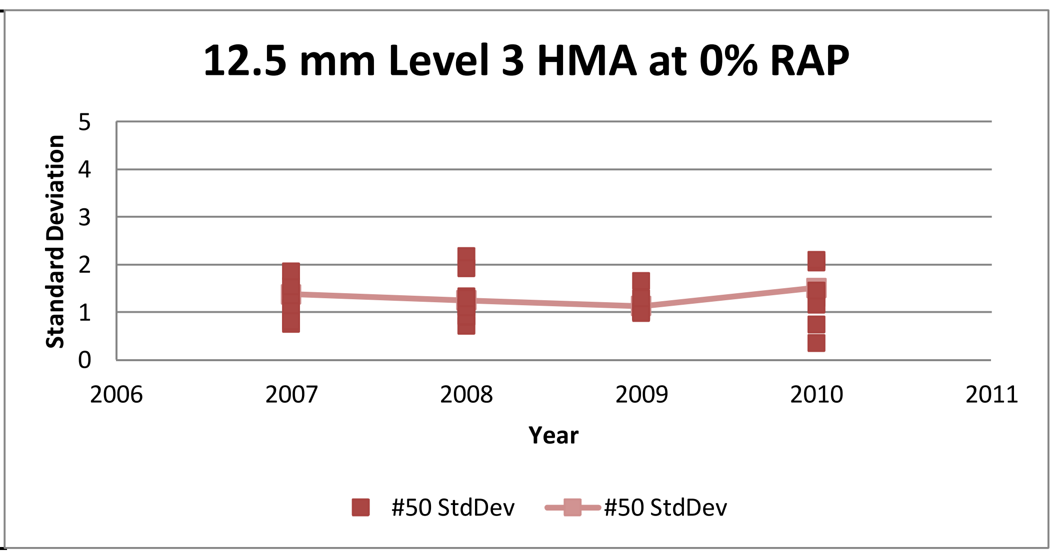
#200 - Percent Passing #200 Sieve



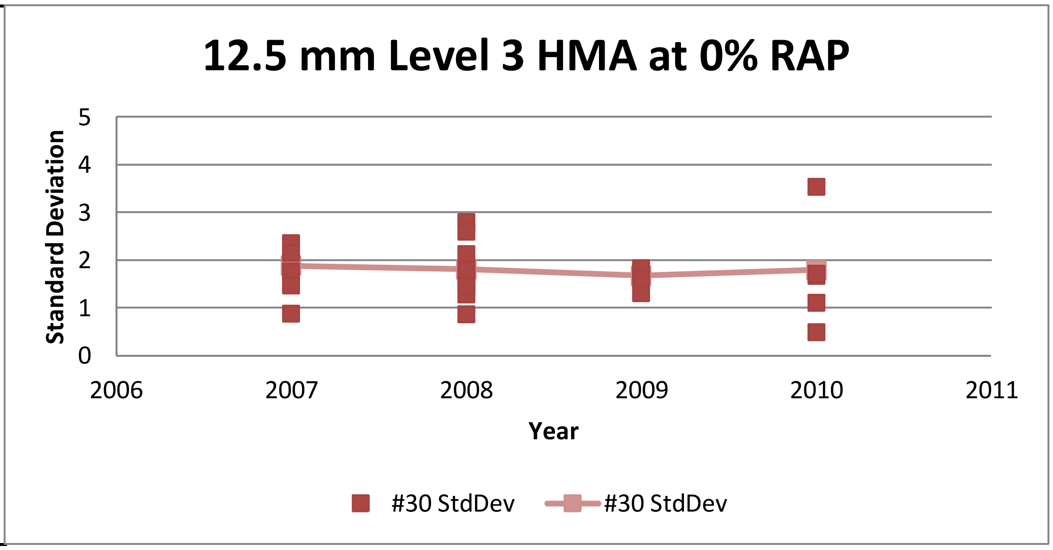
#100 - Percent Passing #100 Sieve



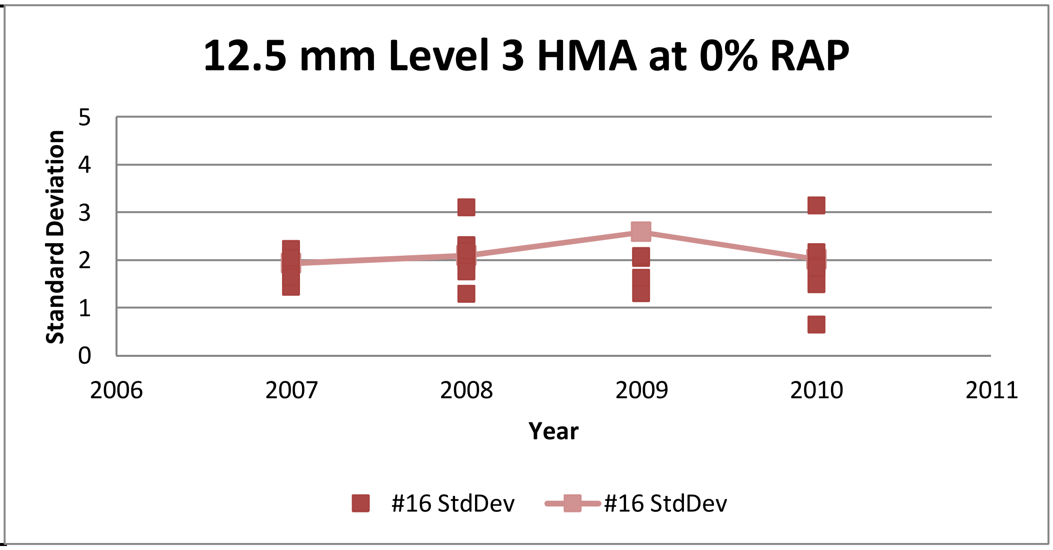
#50 - Percent Passing #50 Sieve



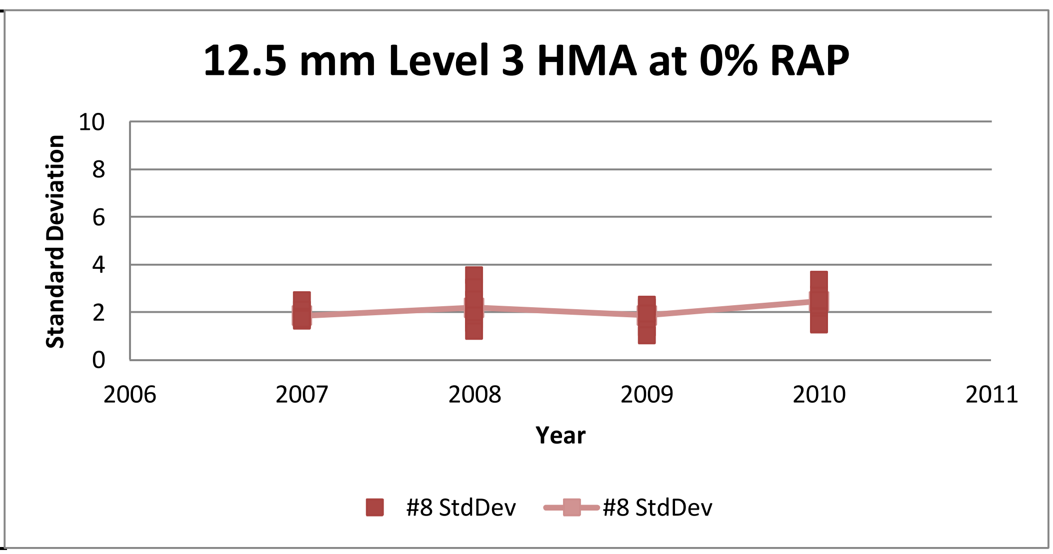
#30 - Percent Passing #30 Sieve



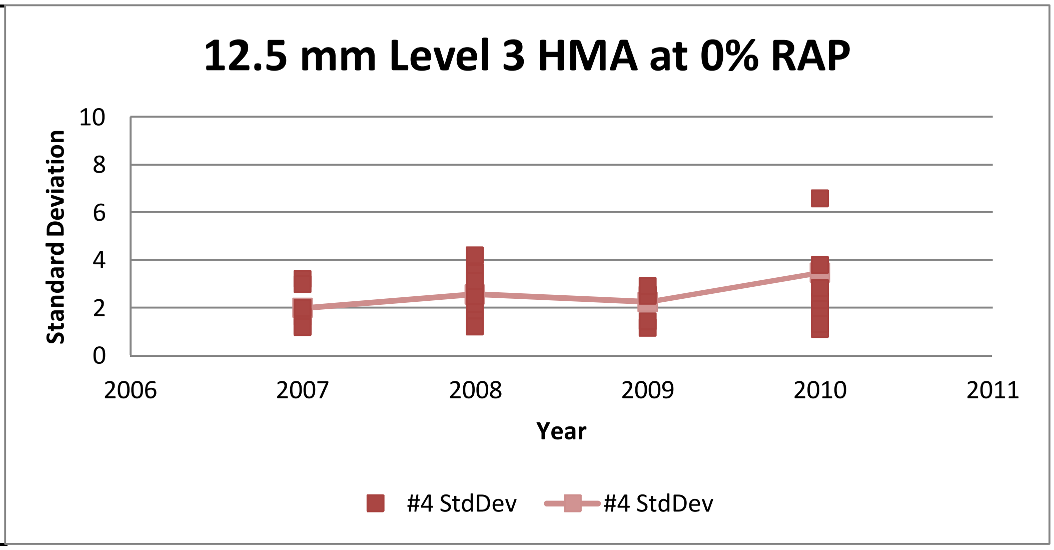
#16 - Percent Passing #16 Sieve



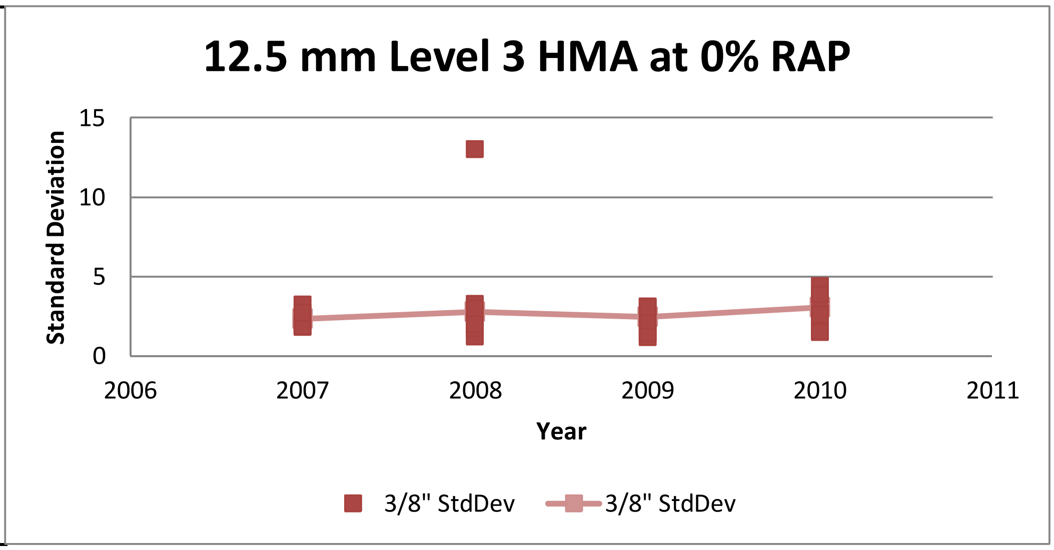
#8 - Percent Passing #8 Sieve



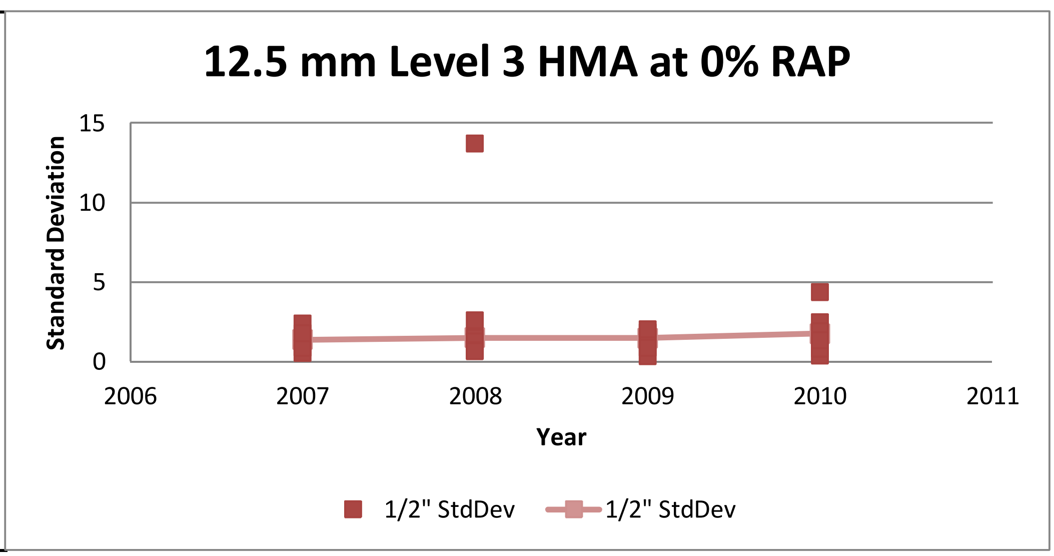
#4 - Percent Passing #4 Sieve



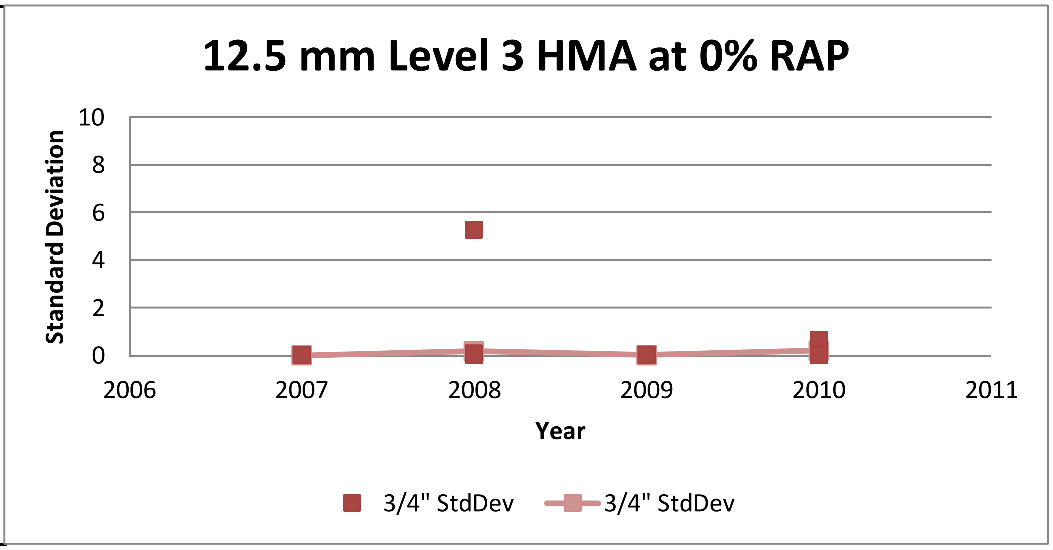
3/8" - Percent Passing 3/8" Sieve



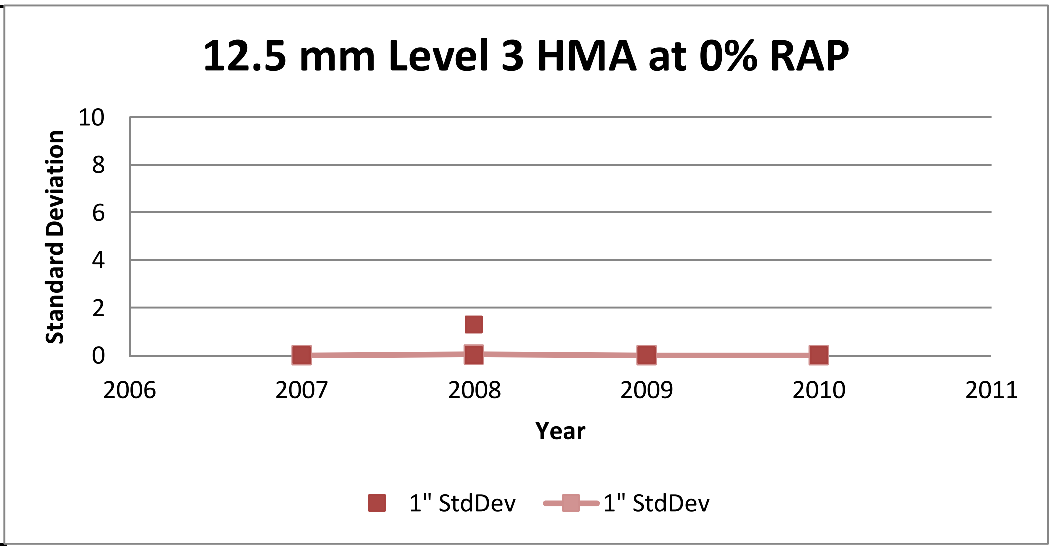
1/2" - Percent Passing 1/2" Sieve



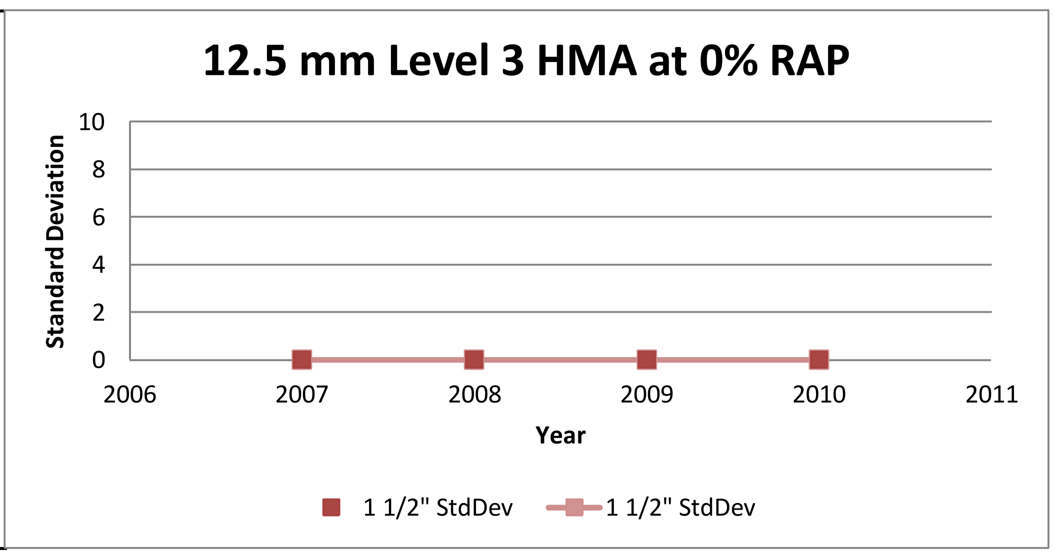
3/4" - Percent Passing 3/4" Sieve



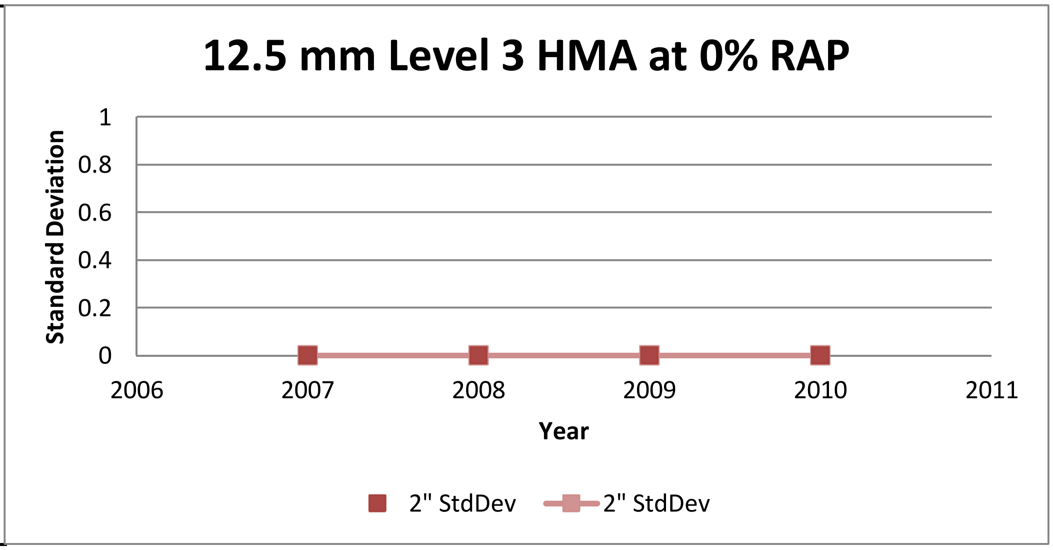
1" - Percent Passing 1" Sieve



1 1/2" - Percent Passing 1 1/2" Sieve



2" - Percent Passing 2" Sieve



Appendix E

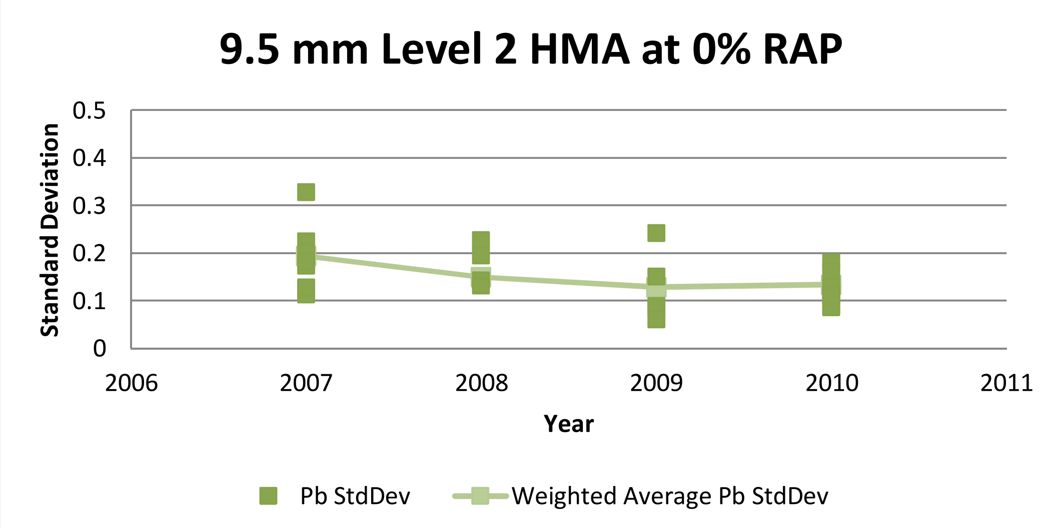
9.5 mm

Level 2

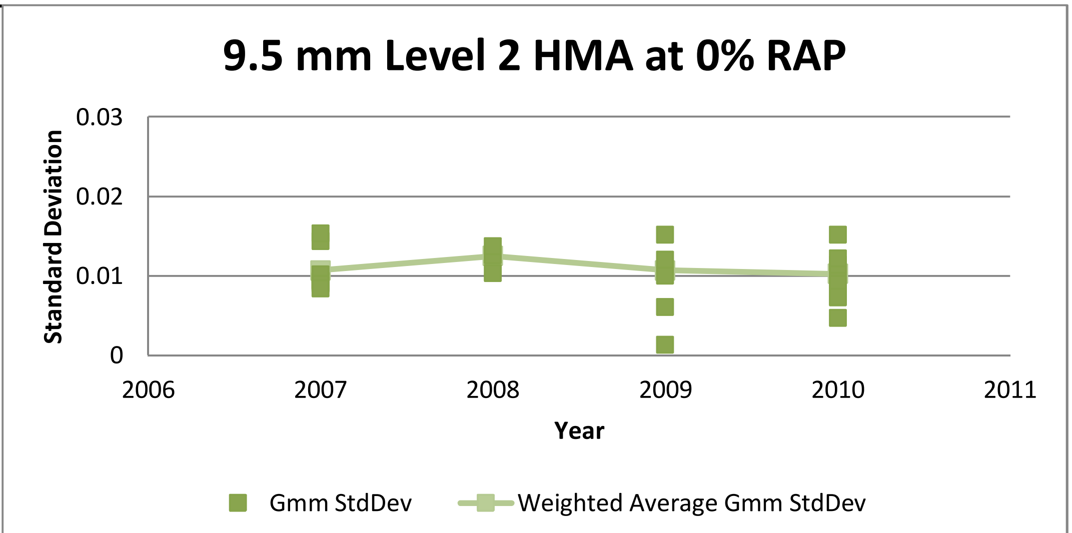
0% RAP

Each datapoint within a year is a different vendor

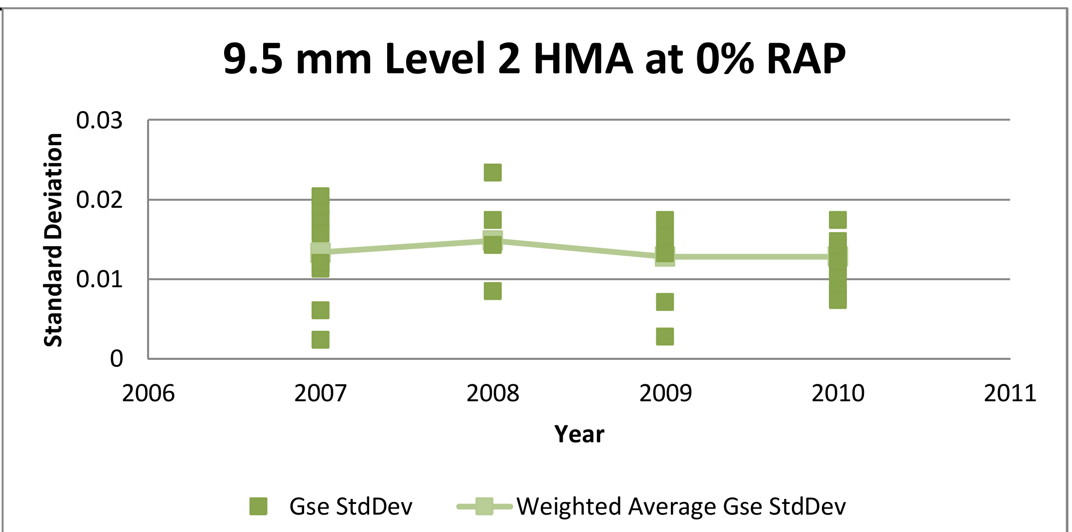
Pb- Percent Binder



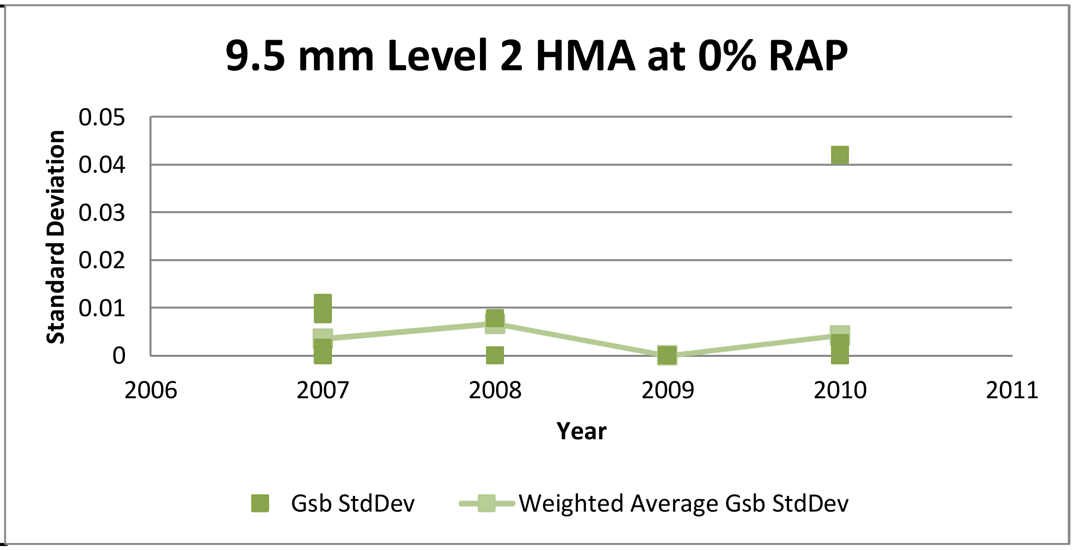
Gmm- Theoretical Maximum Specific Gravity (AASHTO T-209)



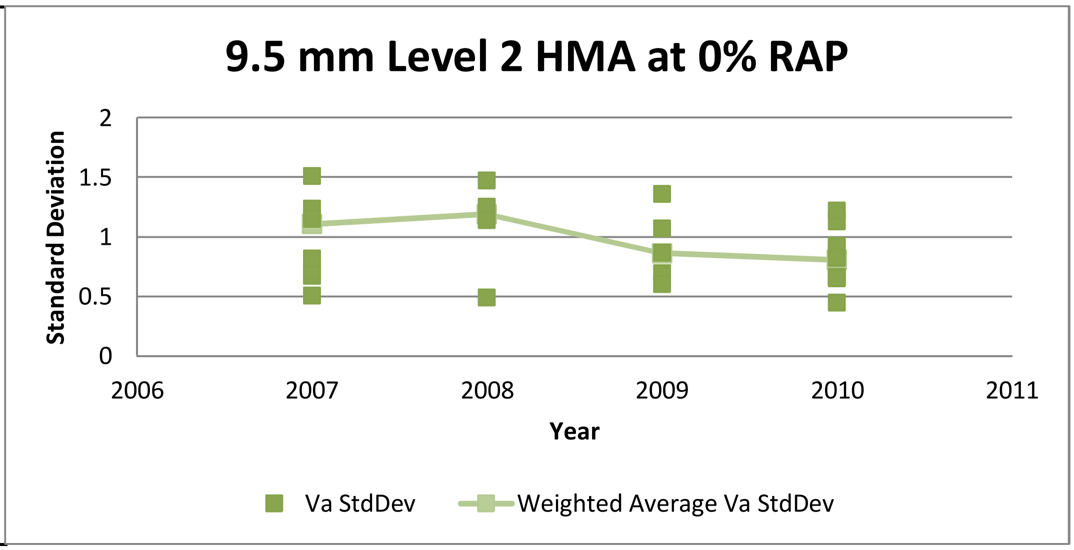
Gse- Effective Specific Gravity



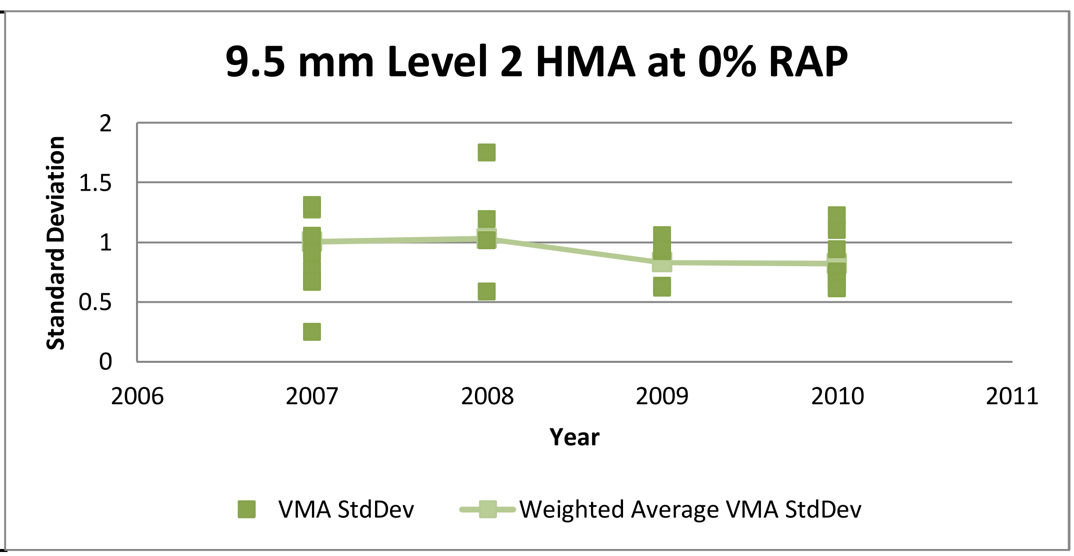
Gsb- Bulk Specific Gravity of the Blended Aggregate



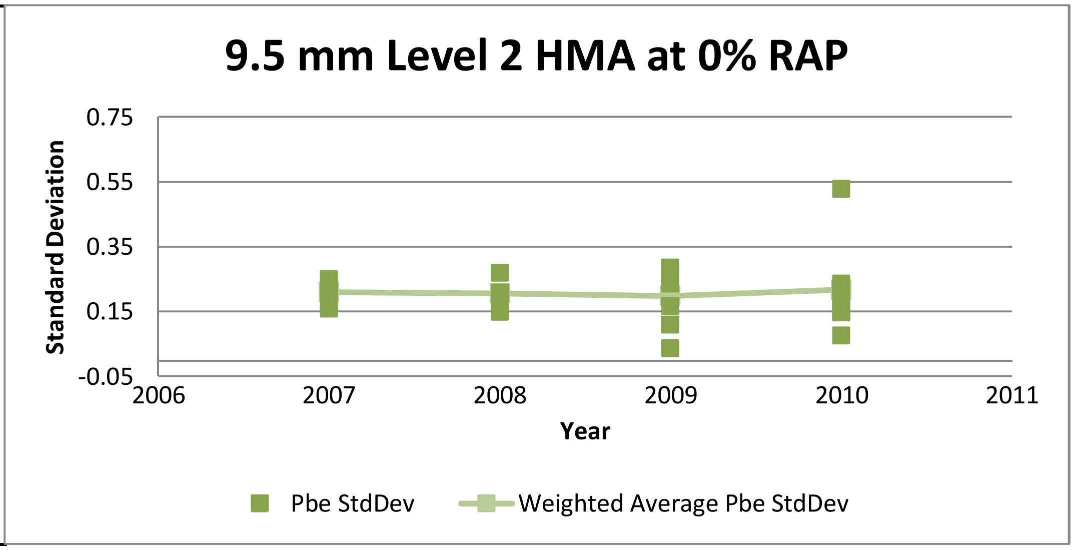
Va- Percent Air Voids



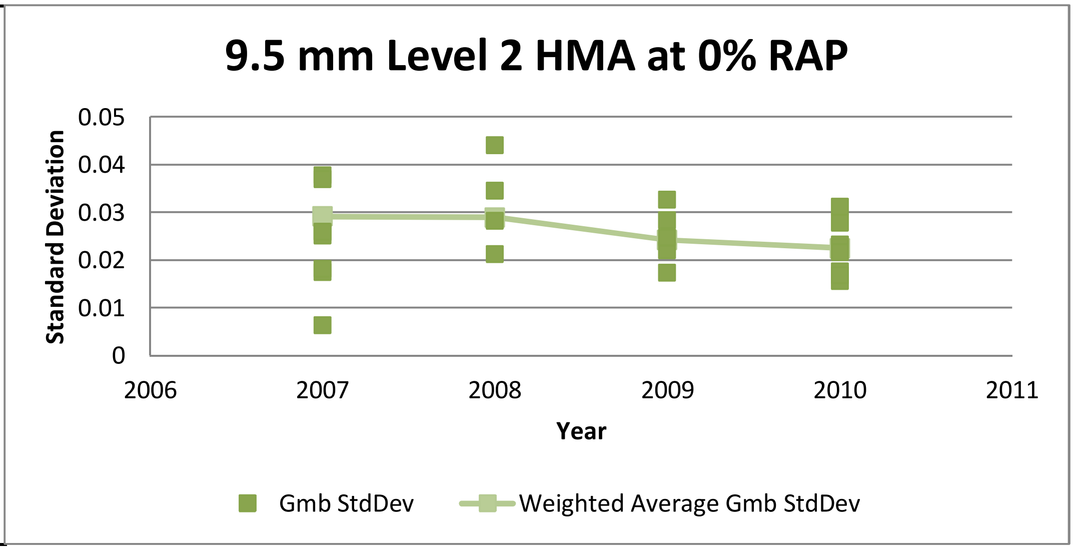
VMA- Voids in the Mineral Aggregate



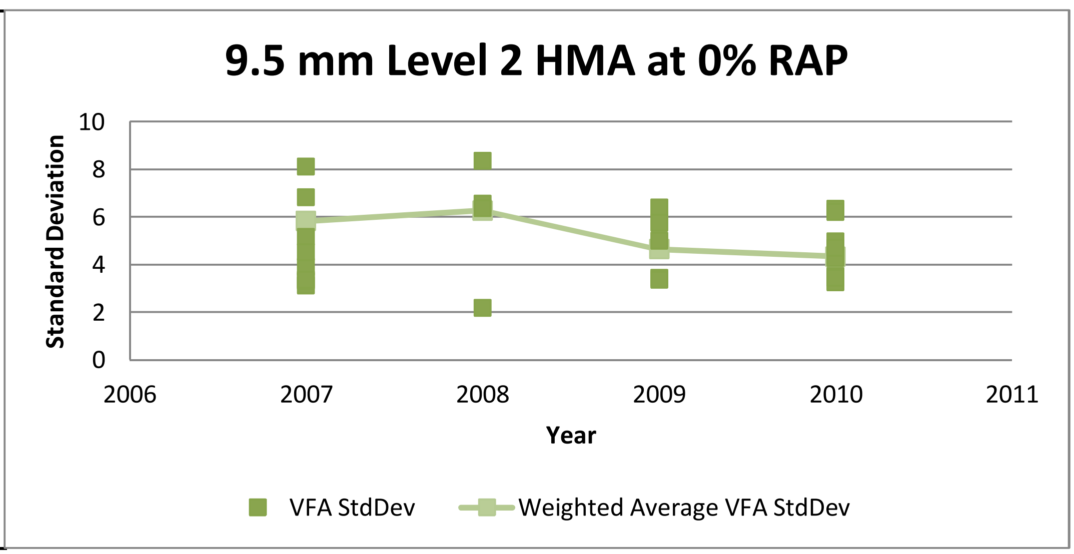
Pbe- Effective Percent Binder



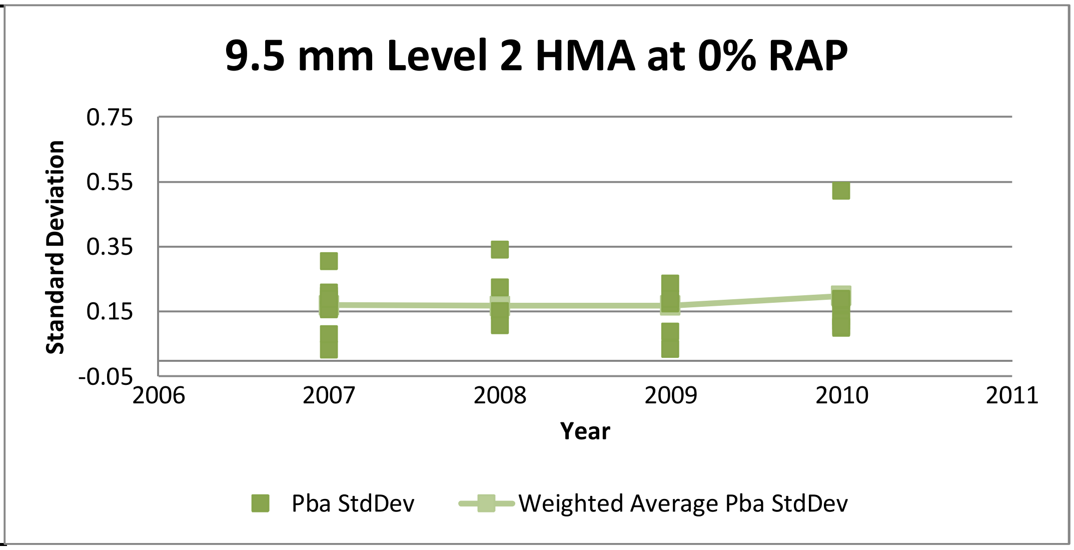
Gmb- Bulk Specific Gravity of the Mix (AASHTO T-166)



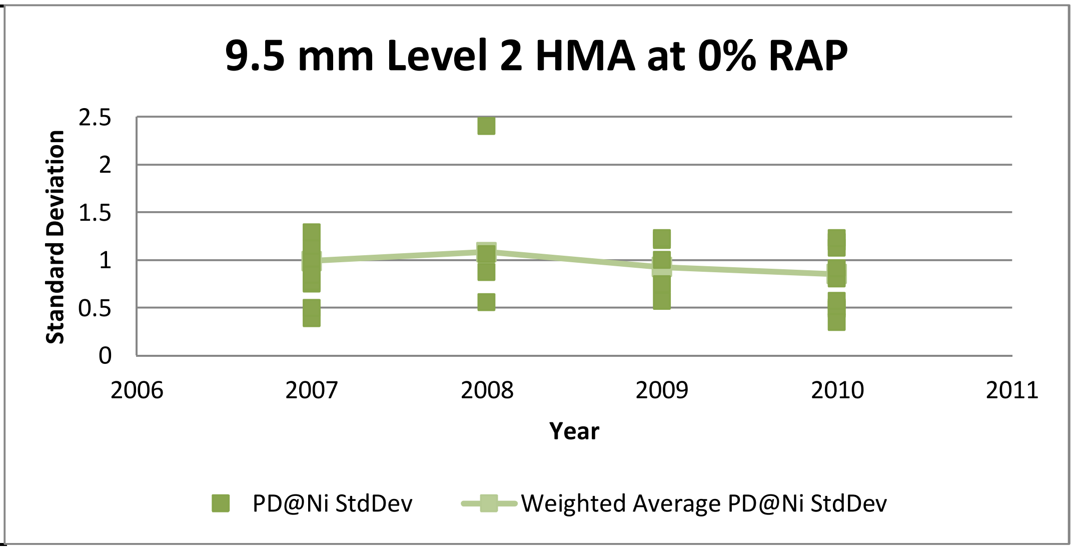
VFA- Voids Filled with Asphalt



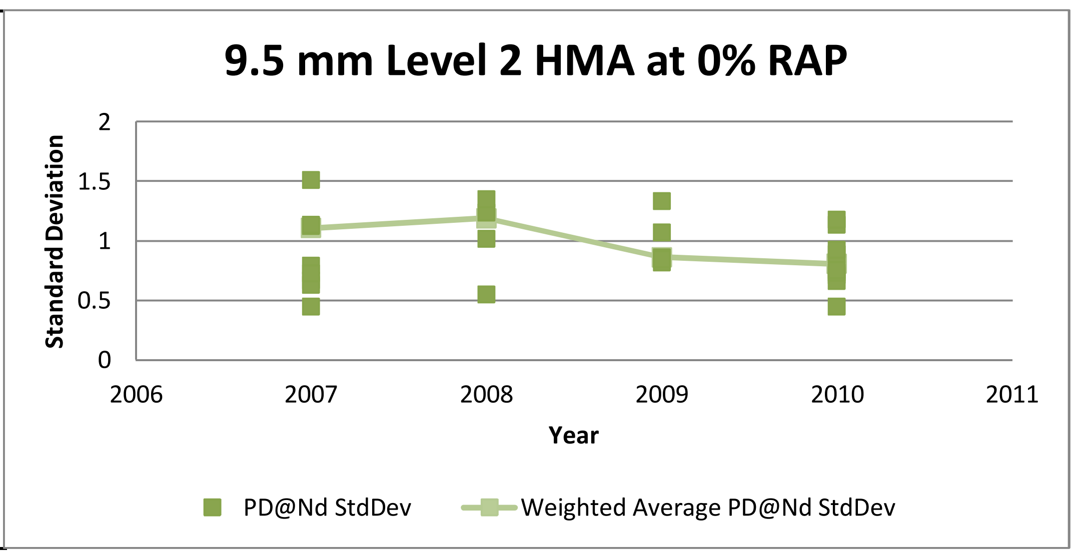
Pba- Percent Absorbed Asphalt



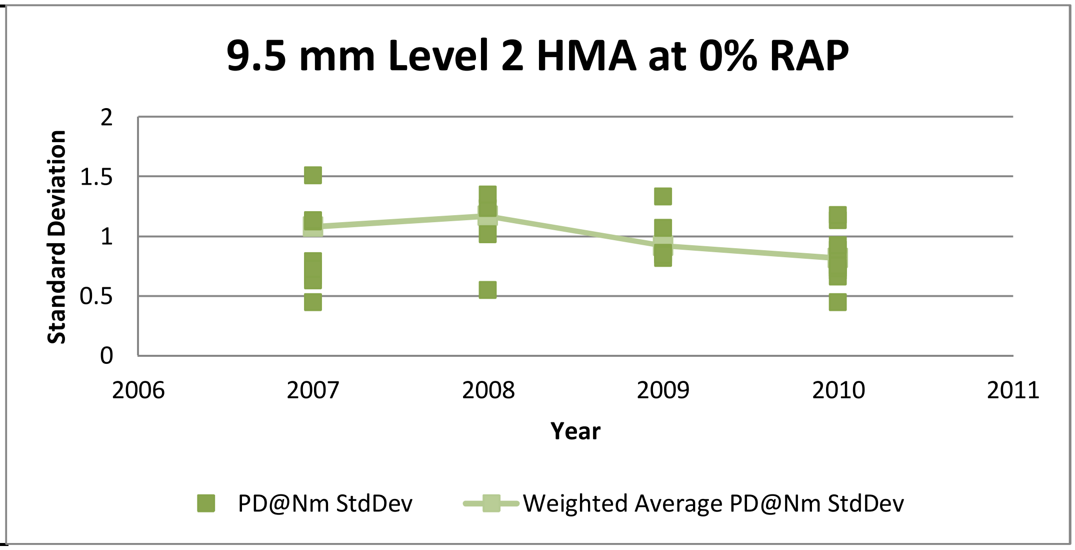
PD@Ni- Percent compaction at the initial number of gyrations



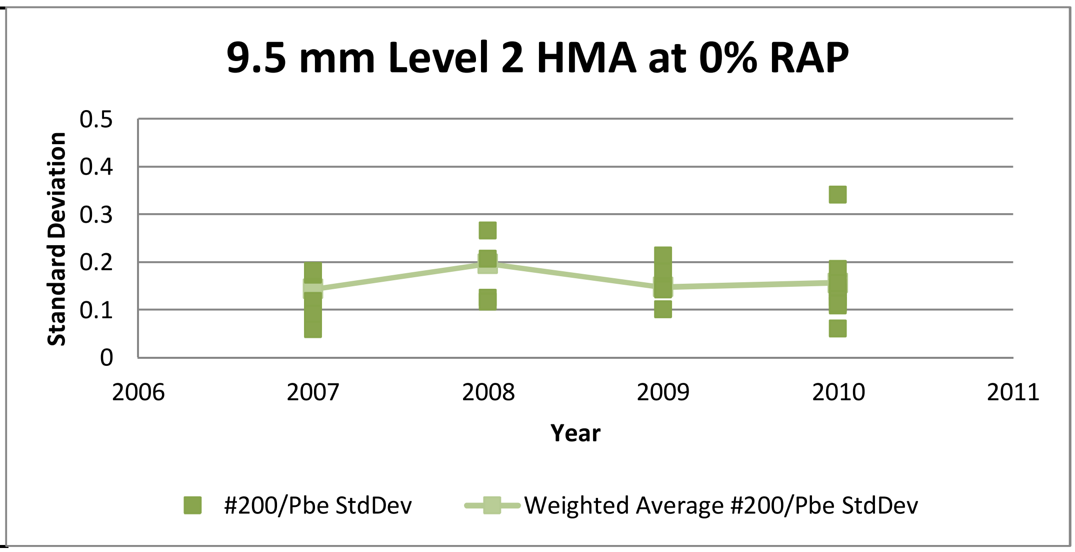
PD@Nd- Percent compaction at the design number of gyrations



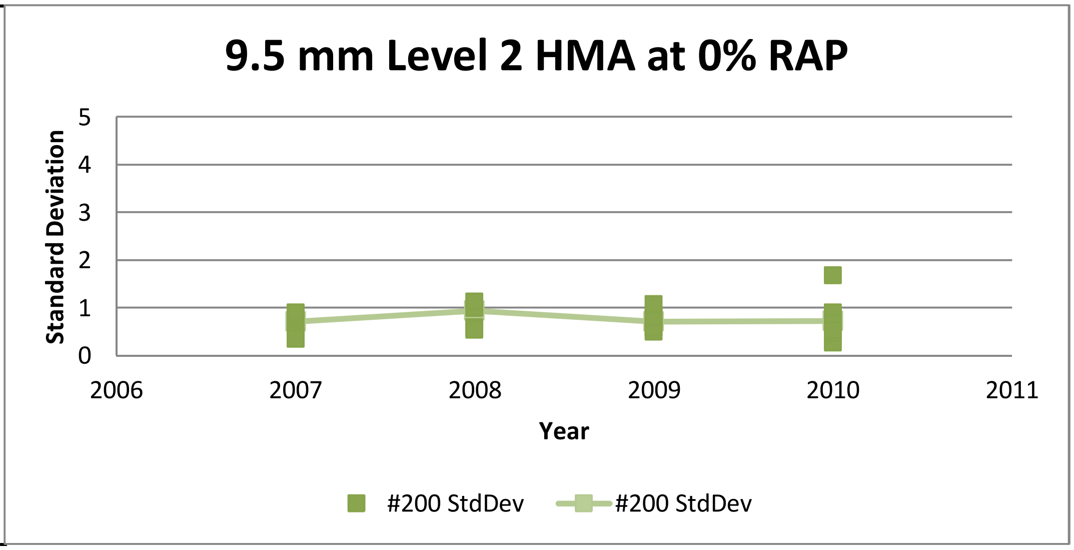
PD@Nm- Percent compaction at the maximum number of gyrations



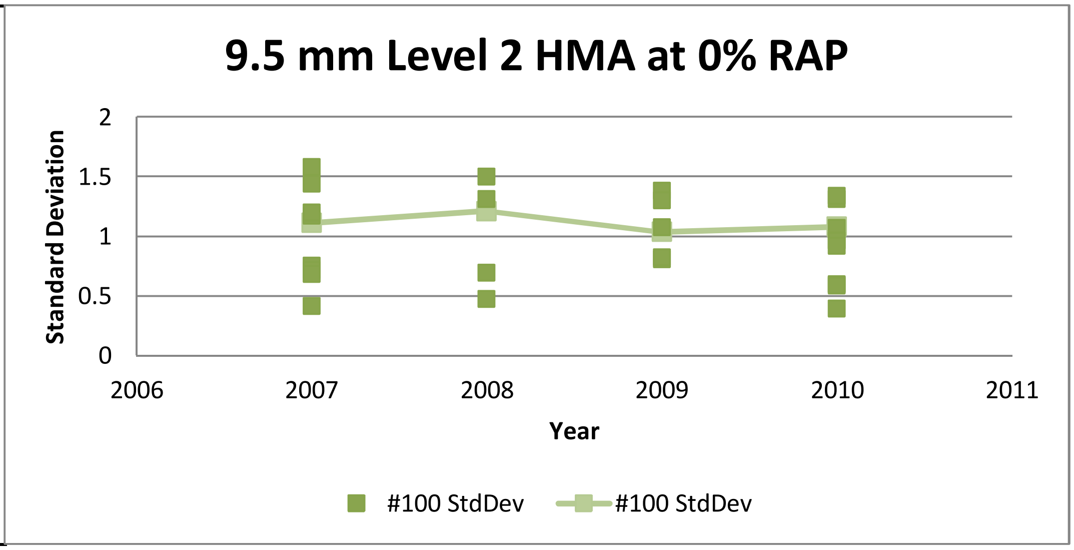
#200/Pbe- Percent passing the #200 sieve divided by the percent binder effective



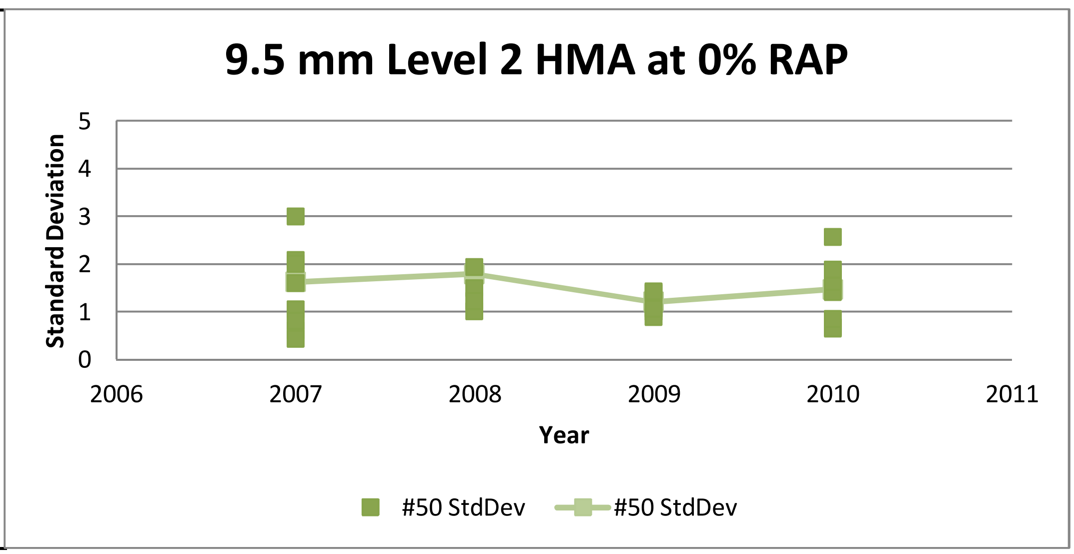
#200 - Percent Passing #200 Sieve



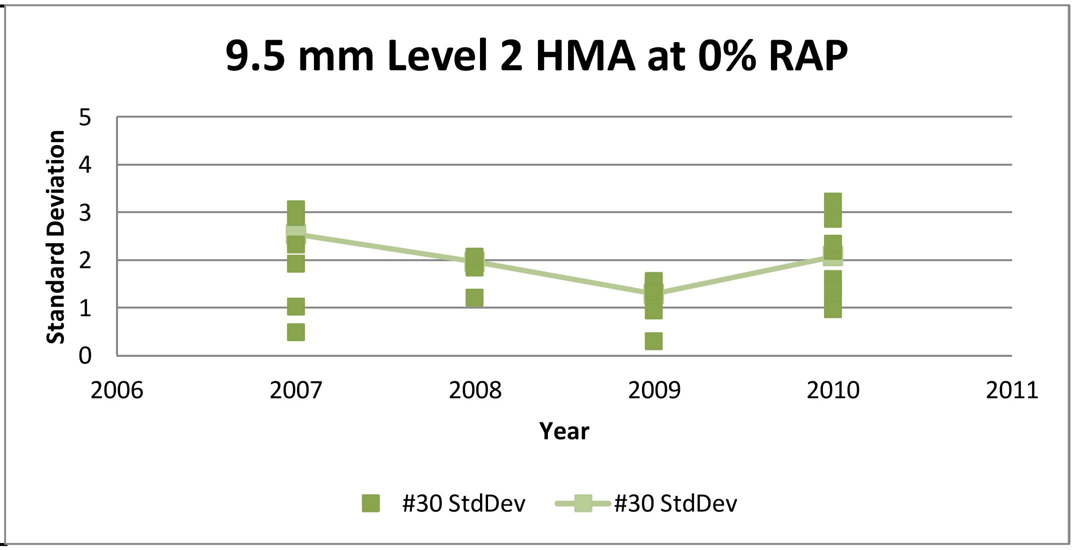
#100 - Percent Passing #100 Sieve



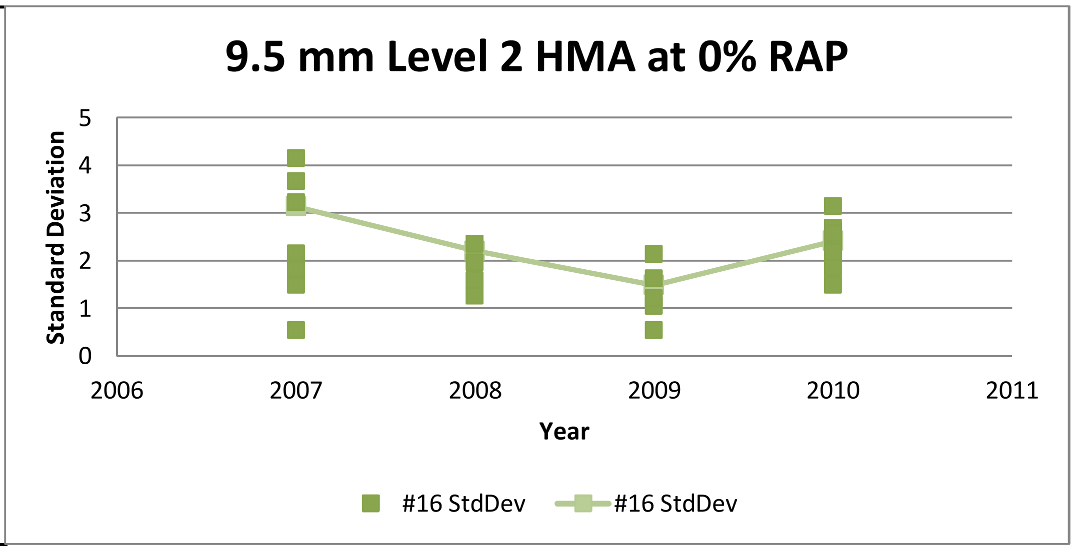
#50 - Percent Passing #50 Sieve



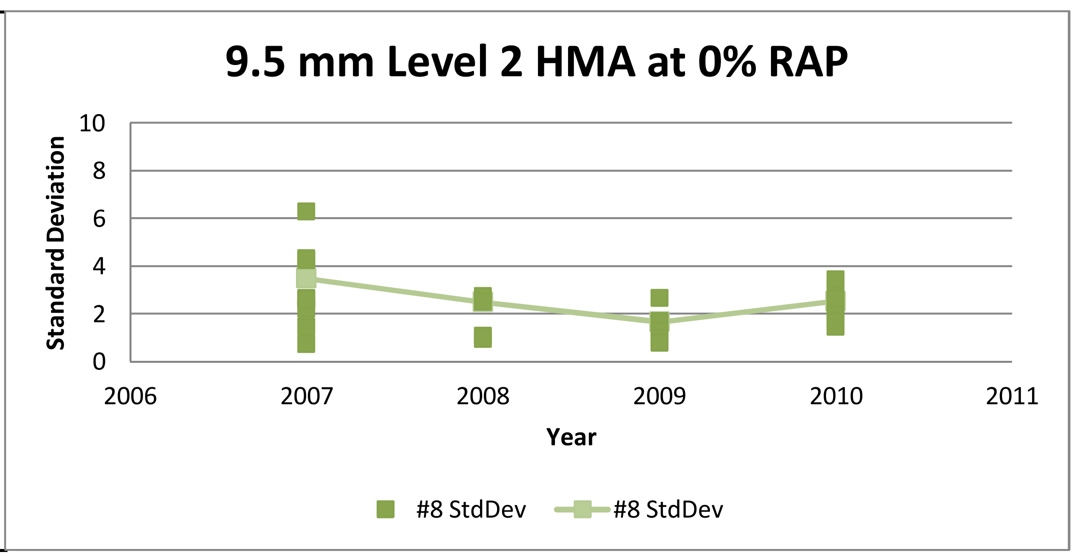
#30 - Percent Passing #30 Sieve



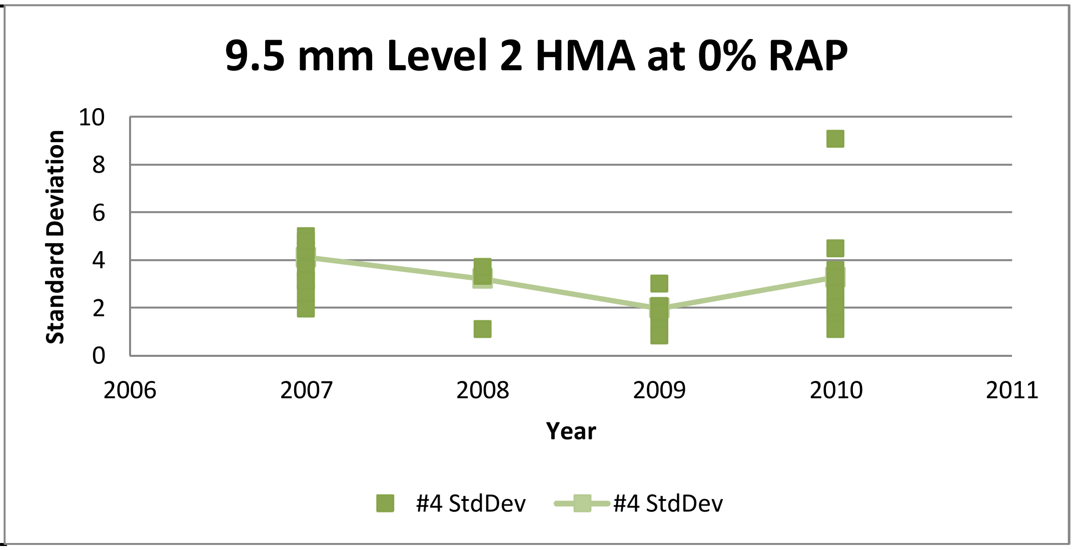
#16 - Percent Passing #16 Sieve



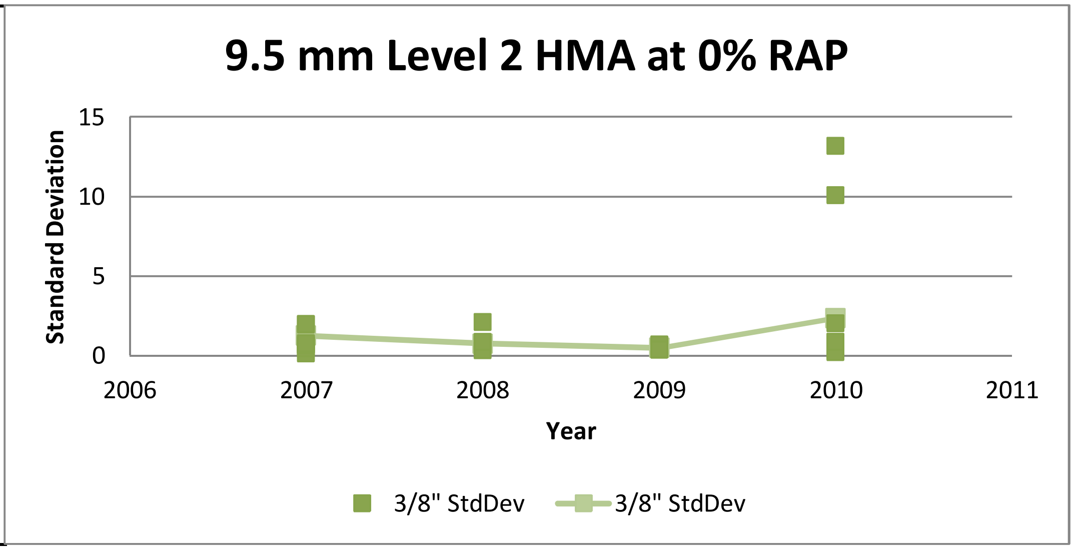
#8 - Percent Passing #8 Sieve



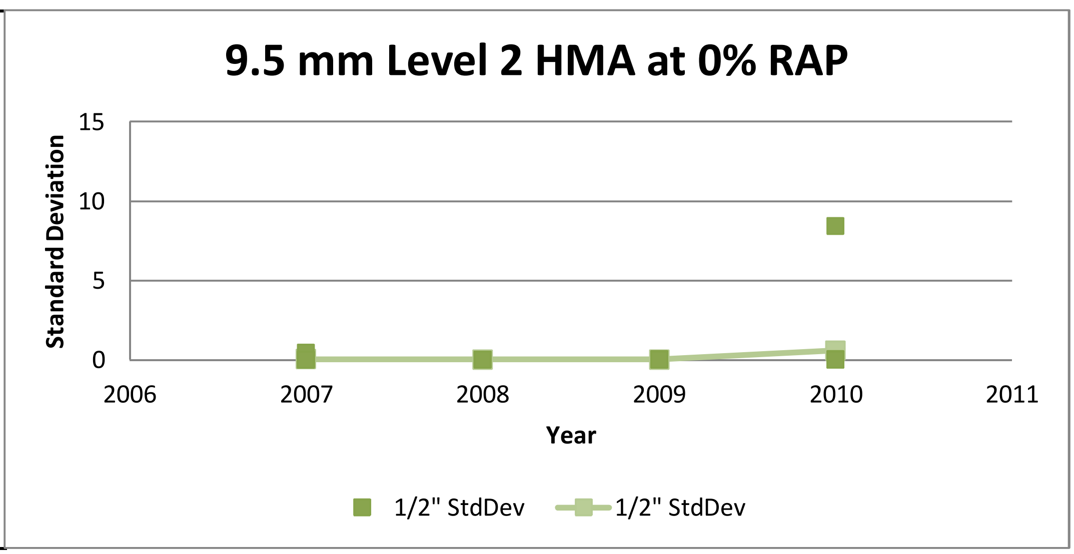
#4 - Percent Passing #4 Sieve



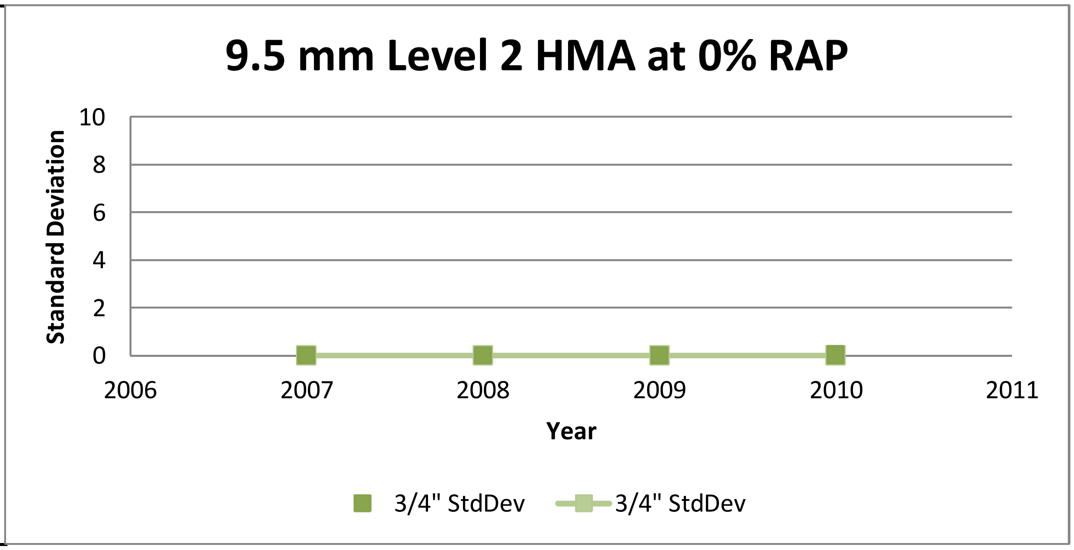
3/8" - Percent Passing 3/8" Sieve



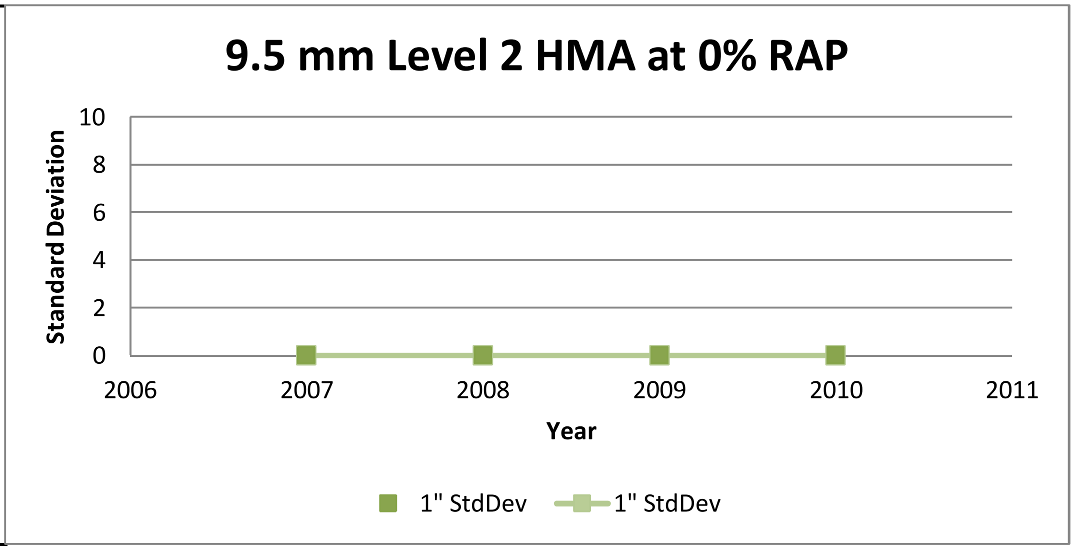
1/2" - Percent Passing 1/2" Sieve



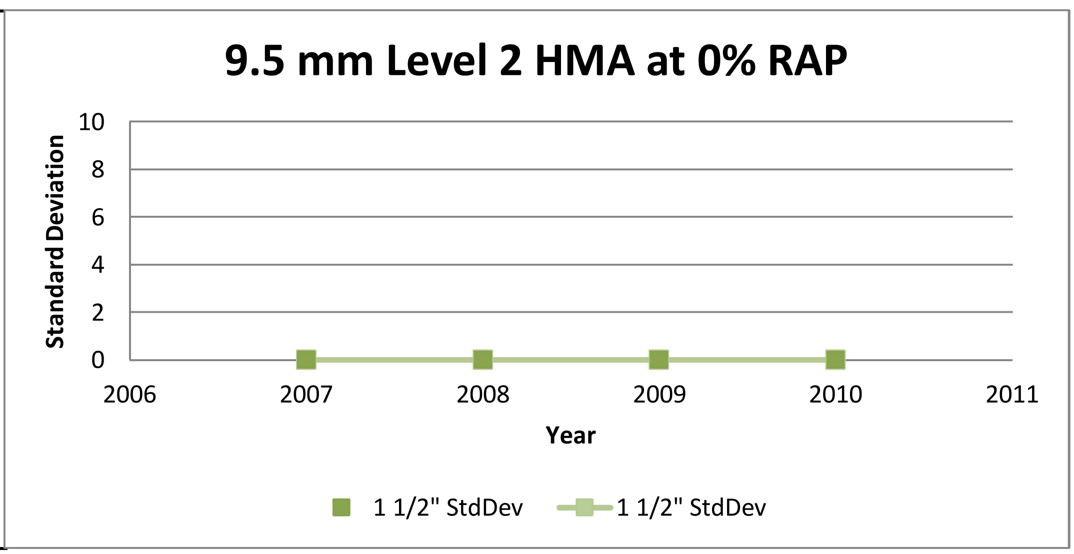
3/4" - Percent Passing 3/4" Sieve



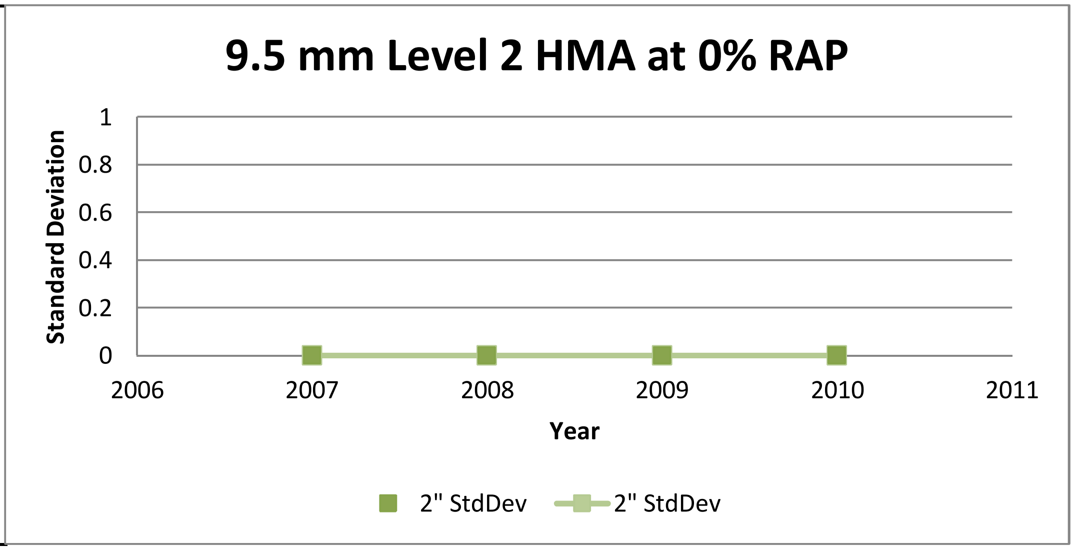
1" - Percent Passing 1" Sieve



1 1/2" - Percent Passing 1 1/2" Sieve



2" - Percent Passing 2" Sieve



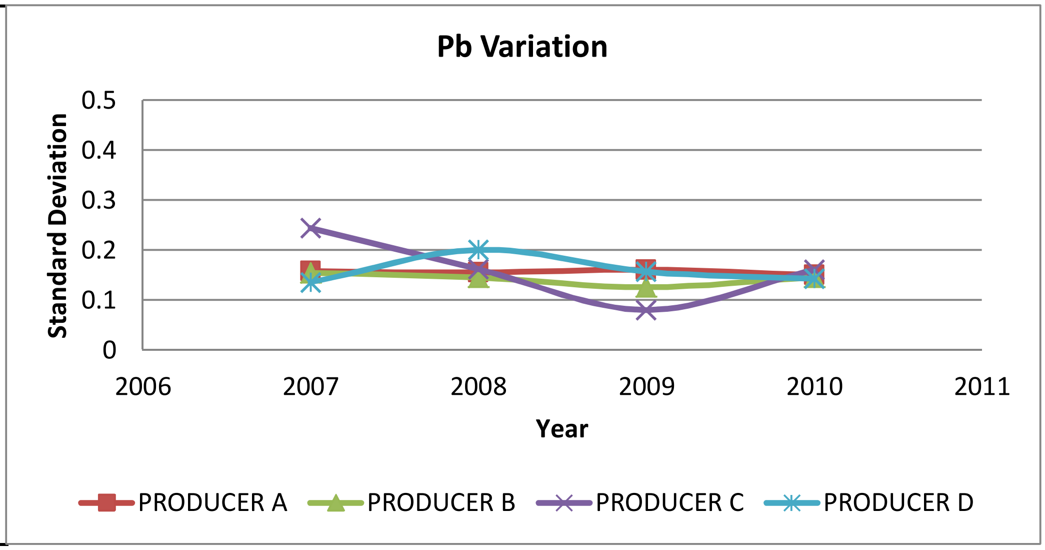
Appendix F

Select Producers

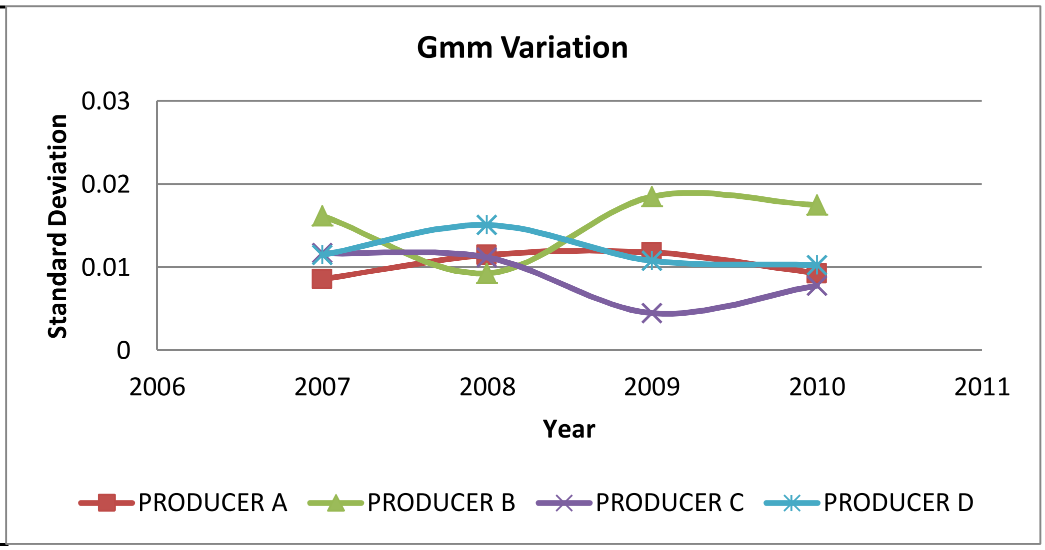
Various Mixes

Each datapoint within a year is a different vendor and potentally a different mix
The mix was held constant for each producer

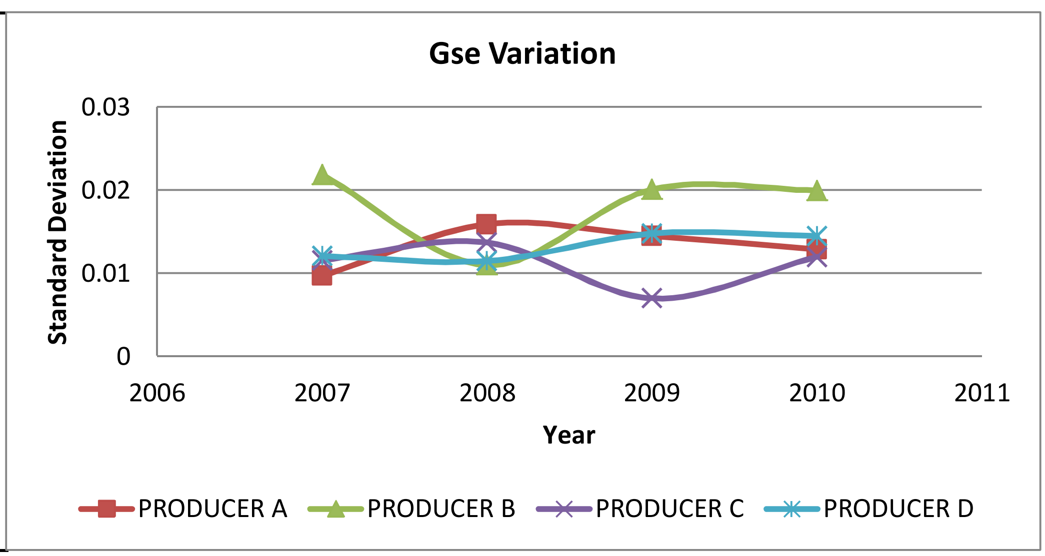
Pb- Percent Binder



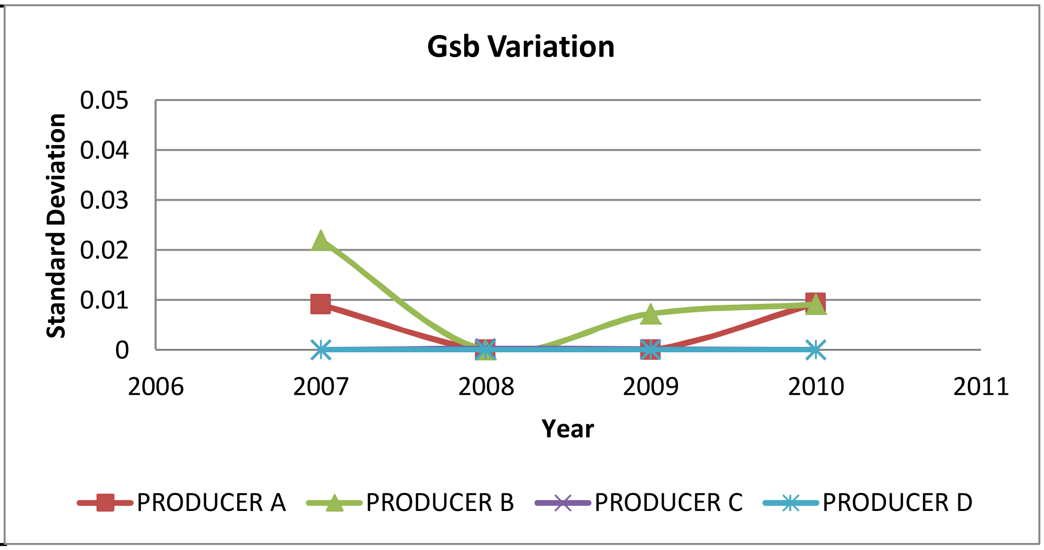
Gmm- Theoretical Maximum Specific Gravity (AASHTO T-209)



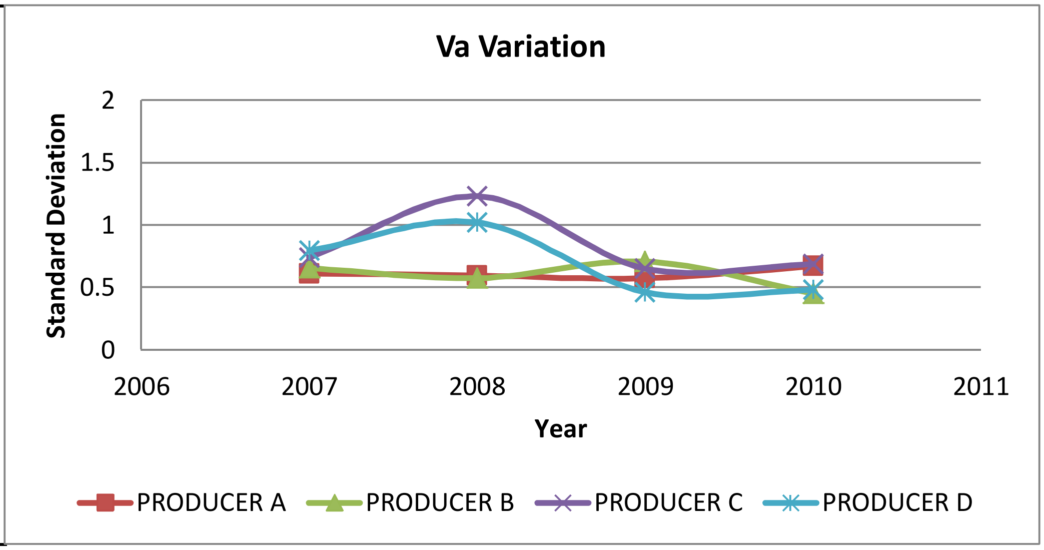
Gse- Effective Specific Gravity



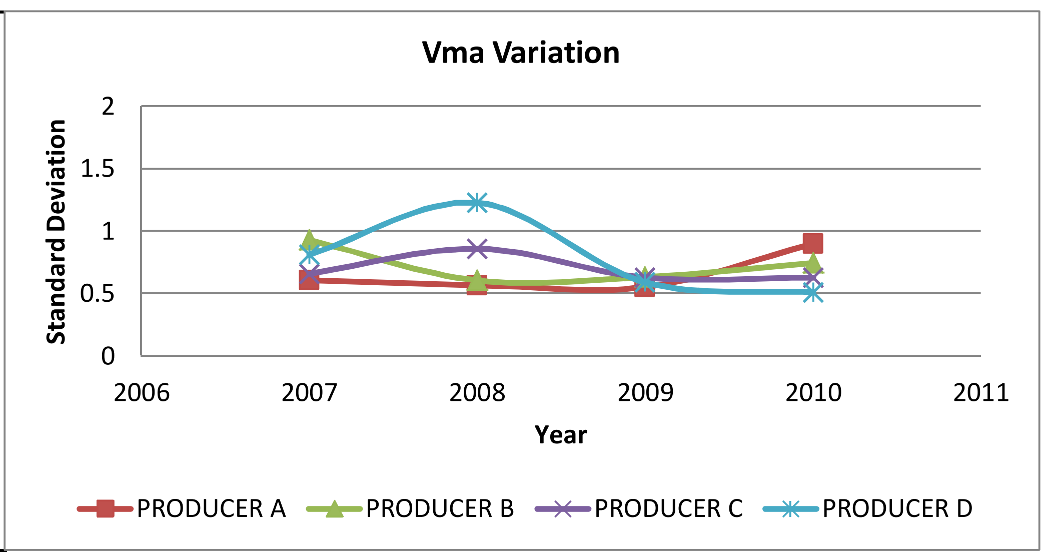
Gsb- Bulk Specific Gravity of the Blended Aggregate



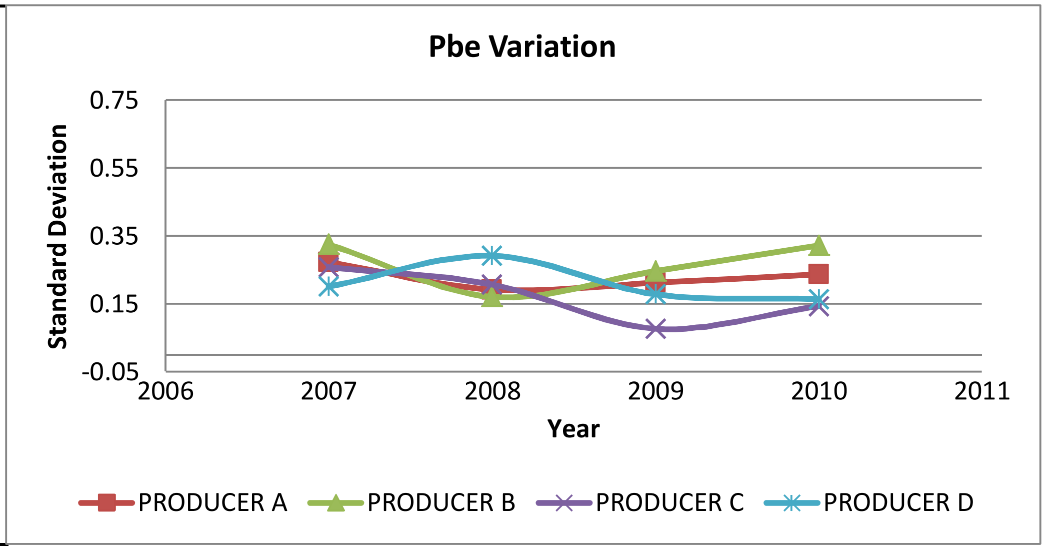
Va- Percent Air Voids



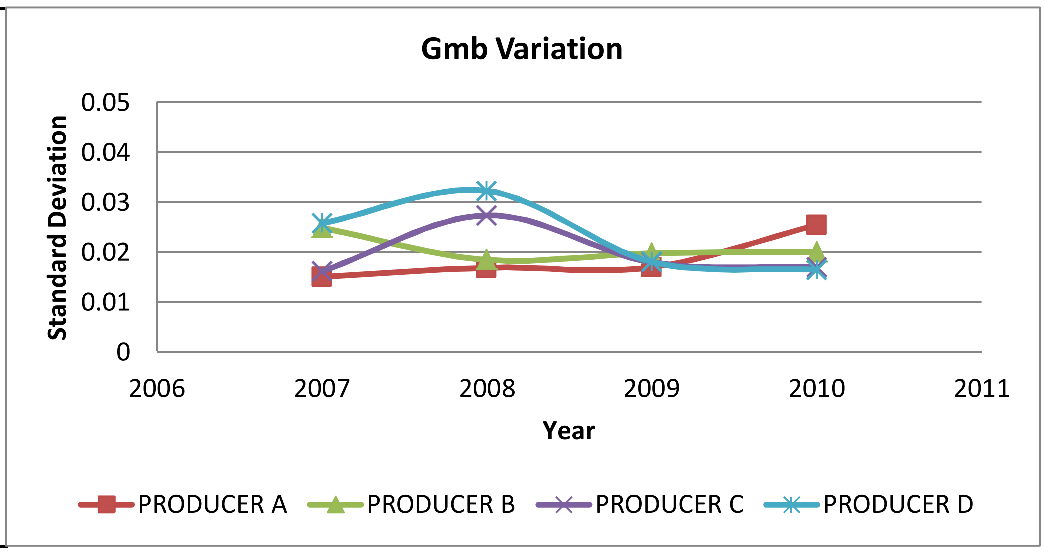
VMA- Voids in the Mineral Aggregate



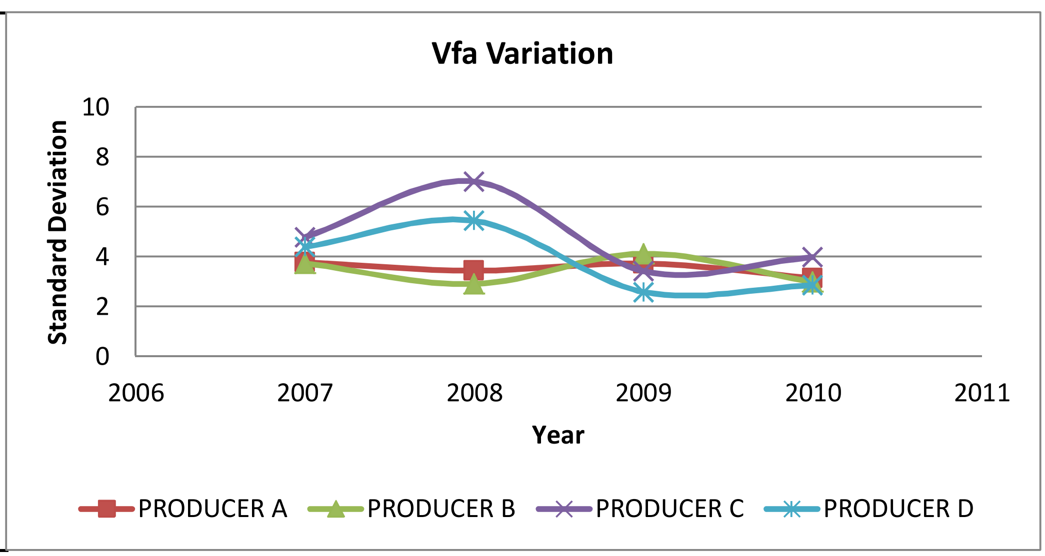
Pbe- Effective Percent Binder



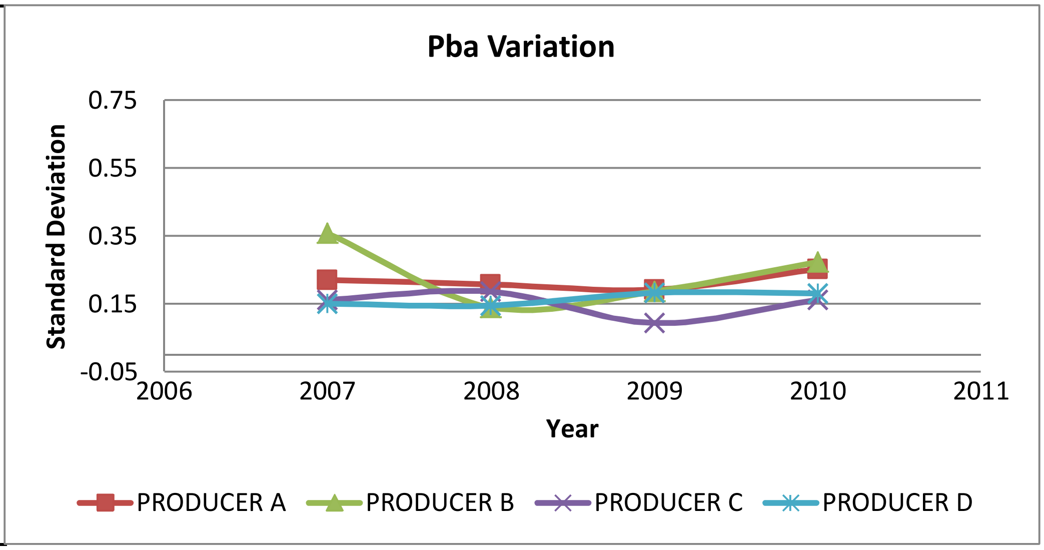
Gmb- Bulk Specific Gravity of the Mix (AASHTO T-166)



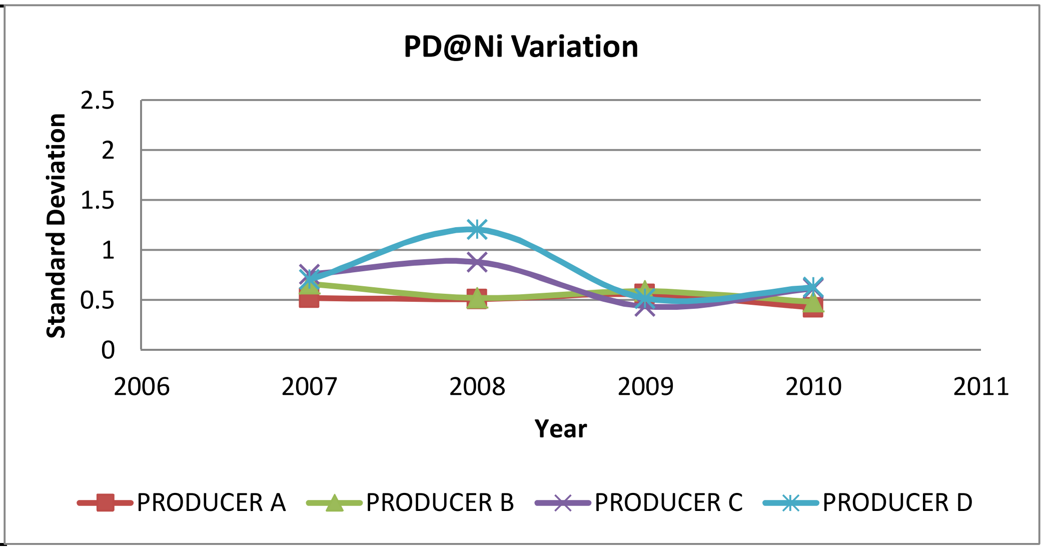
VFA- Voids Filled with Asphalt



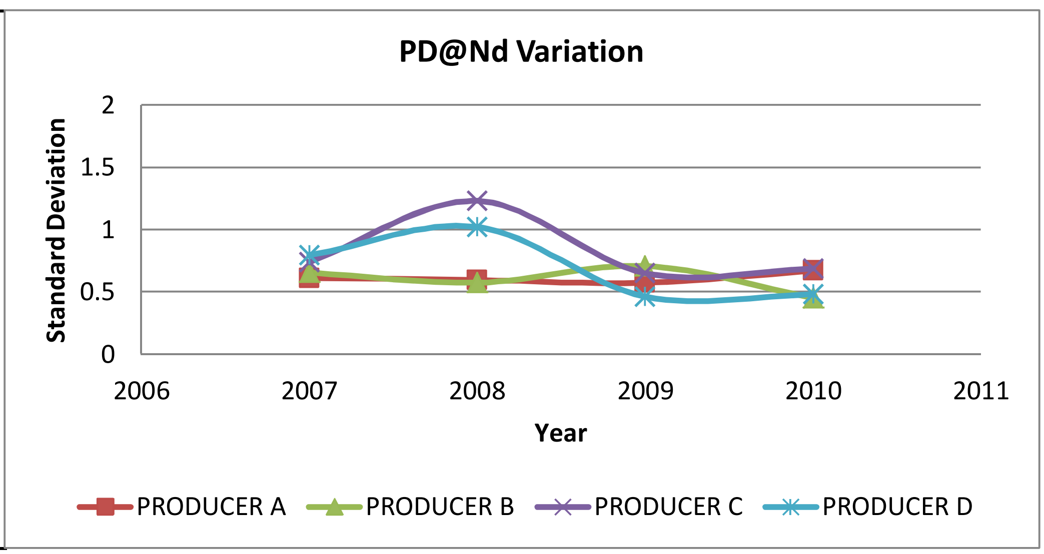
Pba- Percent Absorbed Asphalt



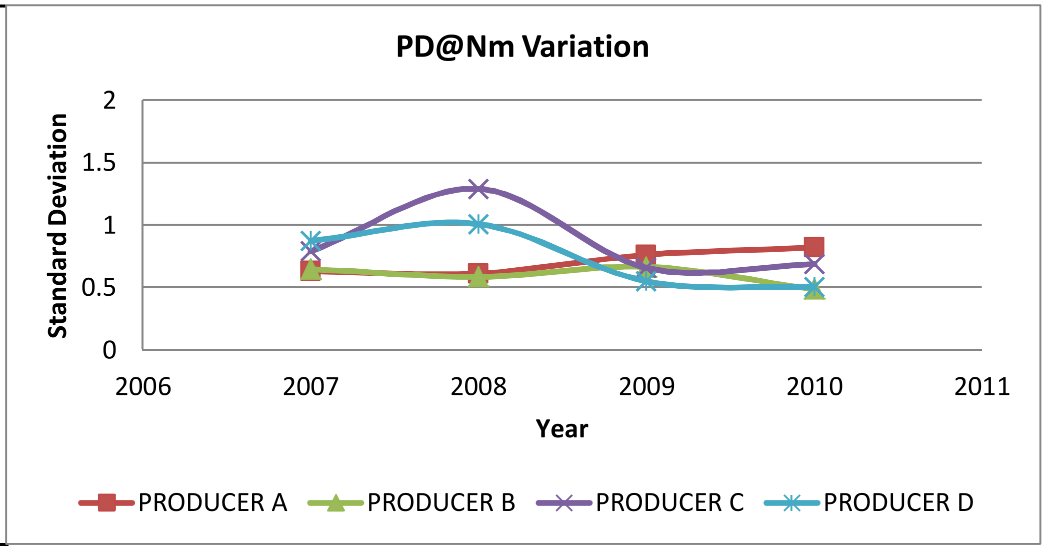
PD@Ni- Percent compaction at the initial number of gyrations



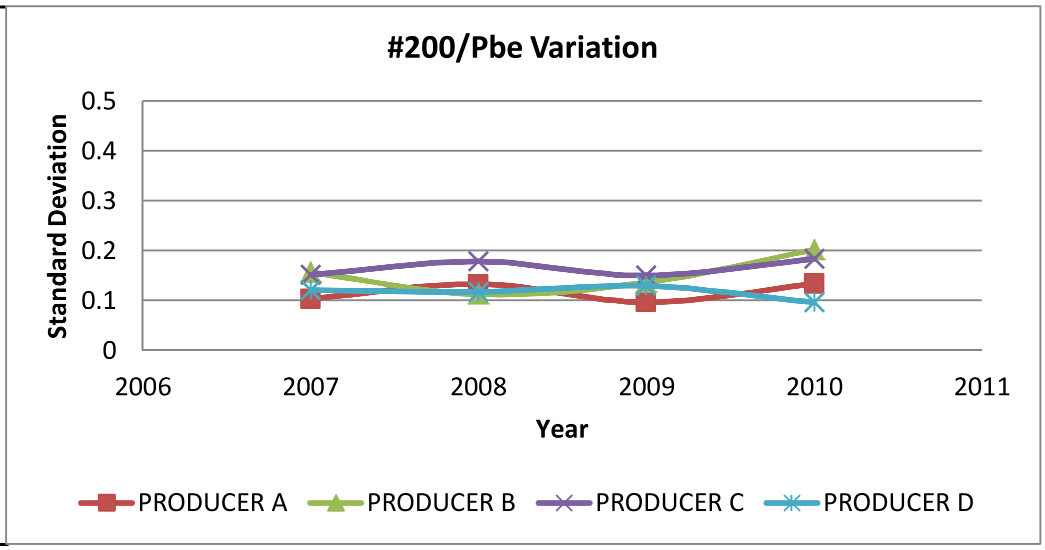
PD@Nd- Percent compaction at the design number of gyrations



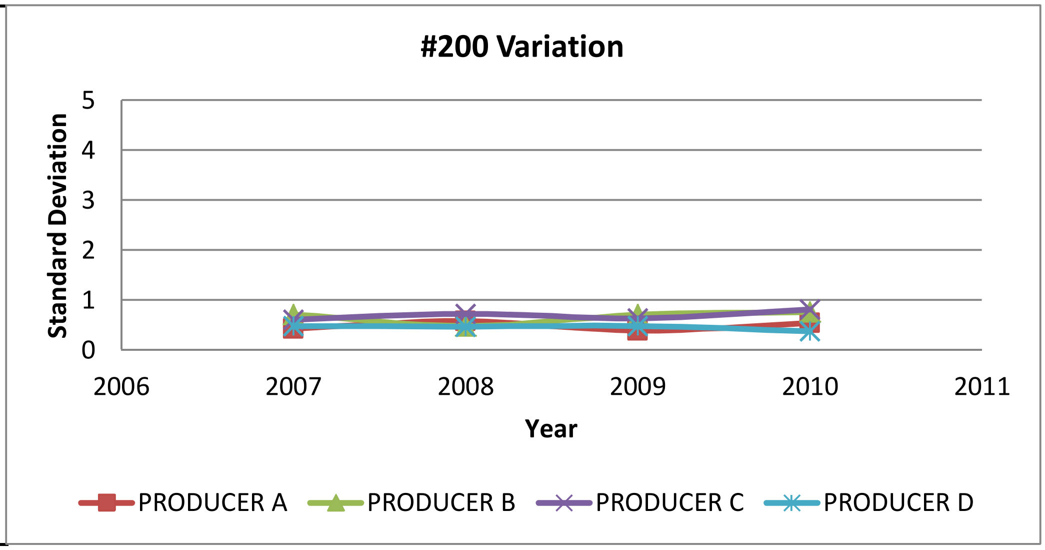
PD@Nm- Percent compaction at the maximum number of gyrations



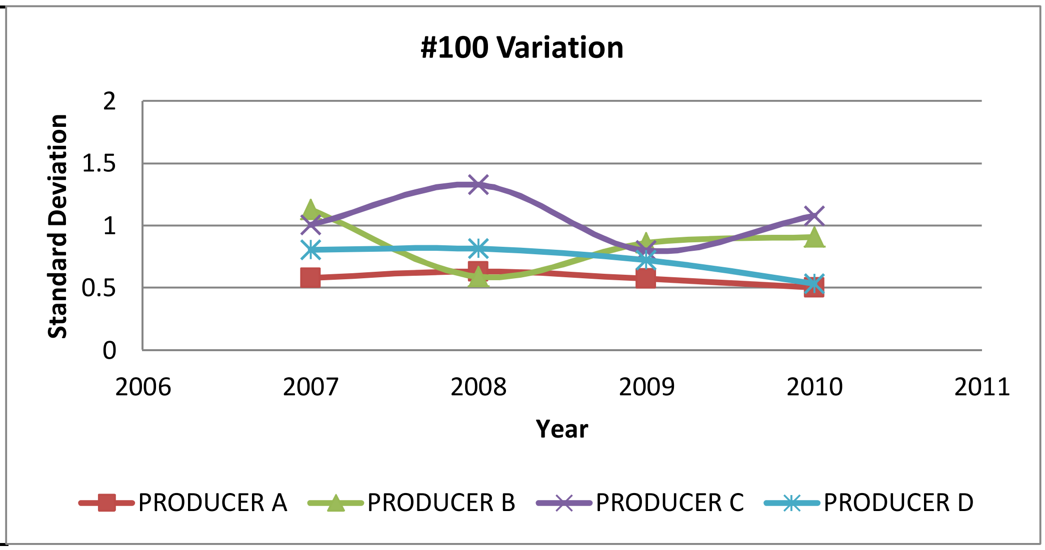
#200/Pbe- Percent passing the #200 sieve divided by the percent binder effective



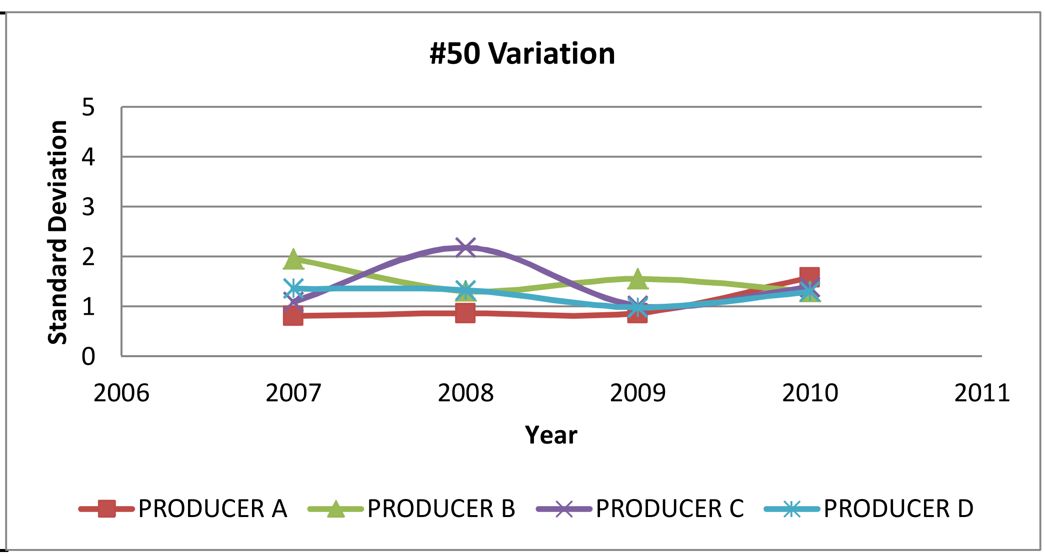
#200 - Percent Passing #200 Sieve



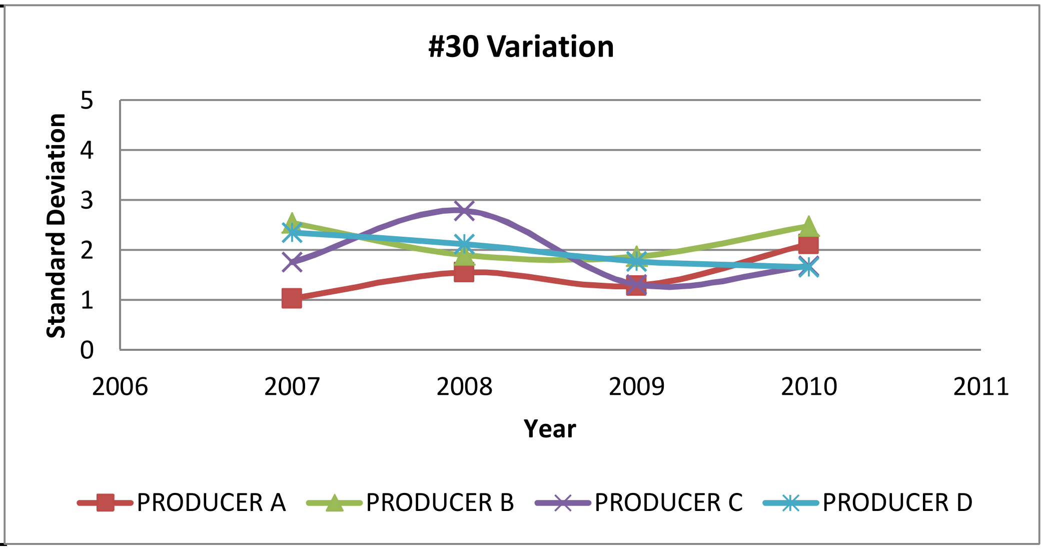
#100 - Percent Passing #100 Sieve



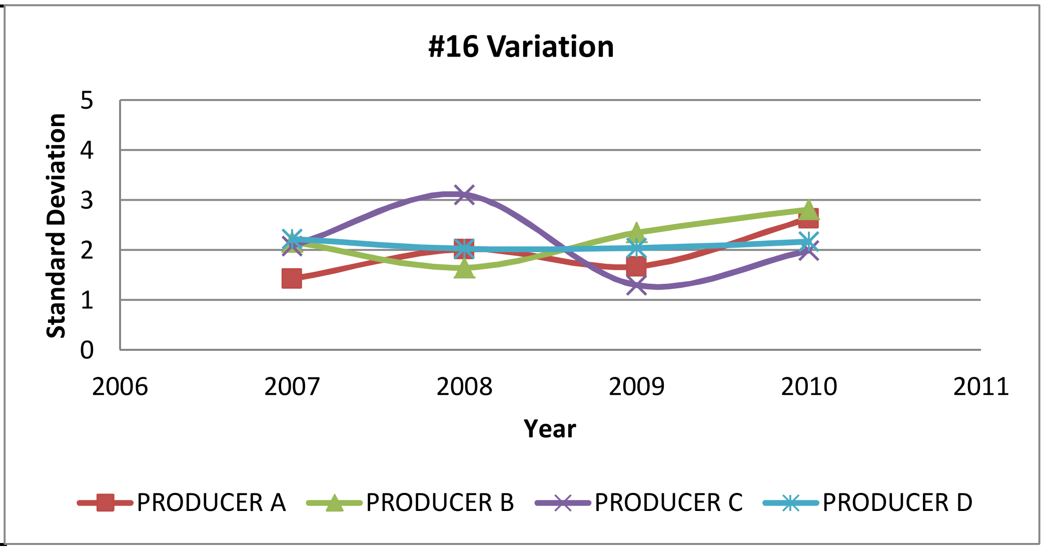
#50 - Percent Passing #50 Sieve



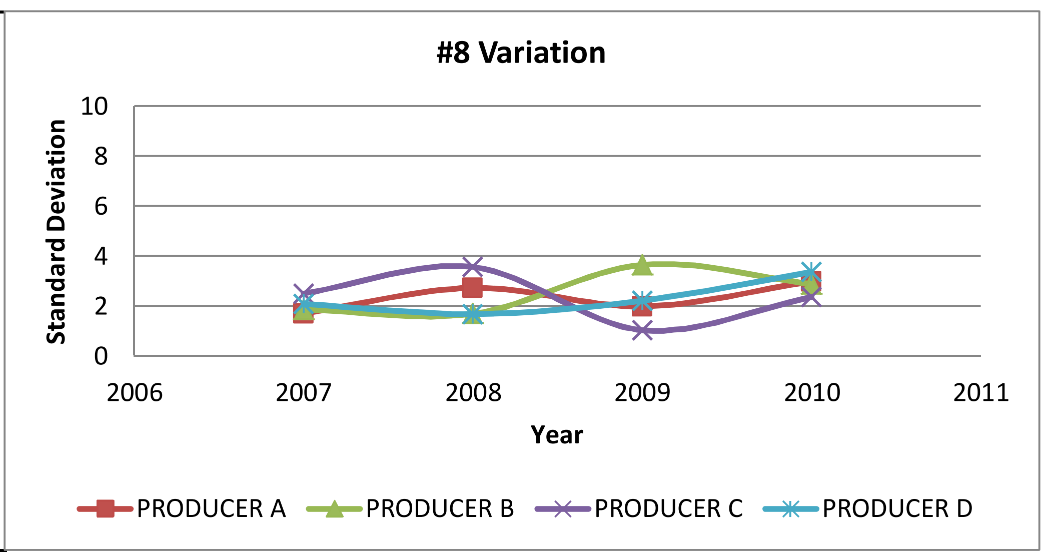
#30 - Percent Passing #30 Sieve



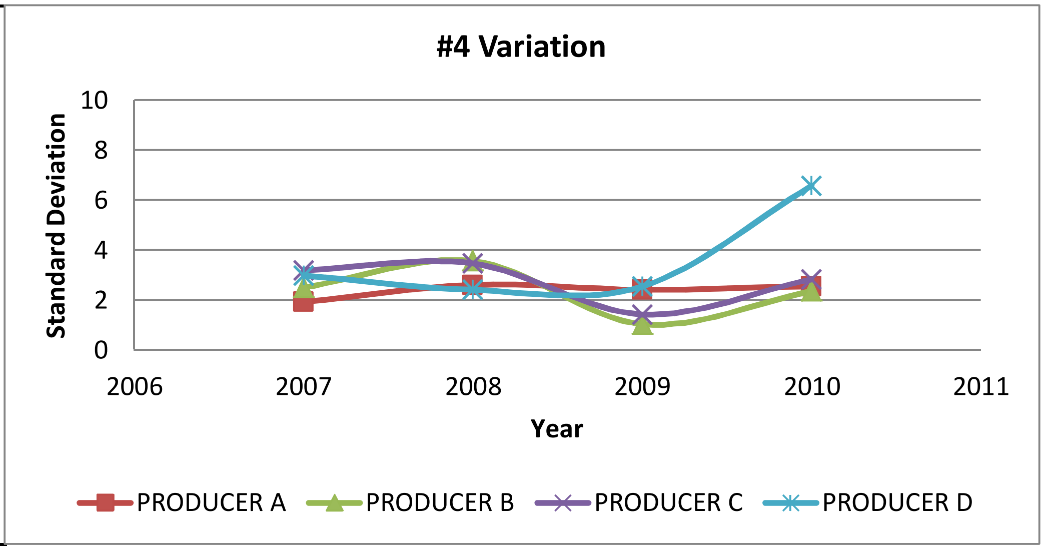
#16 - Percent Passing #16 Sieve



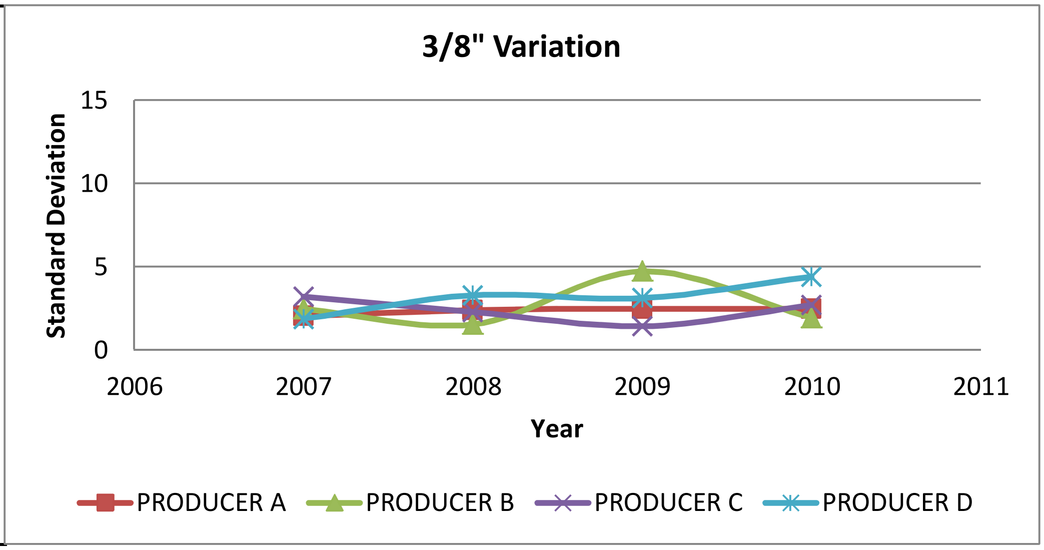
#8 - Percent Passing #8 Sieve



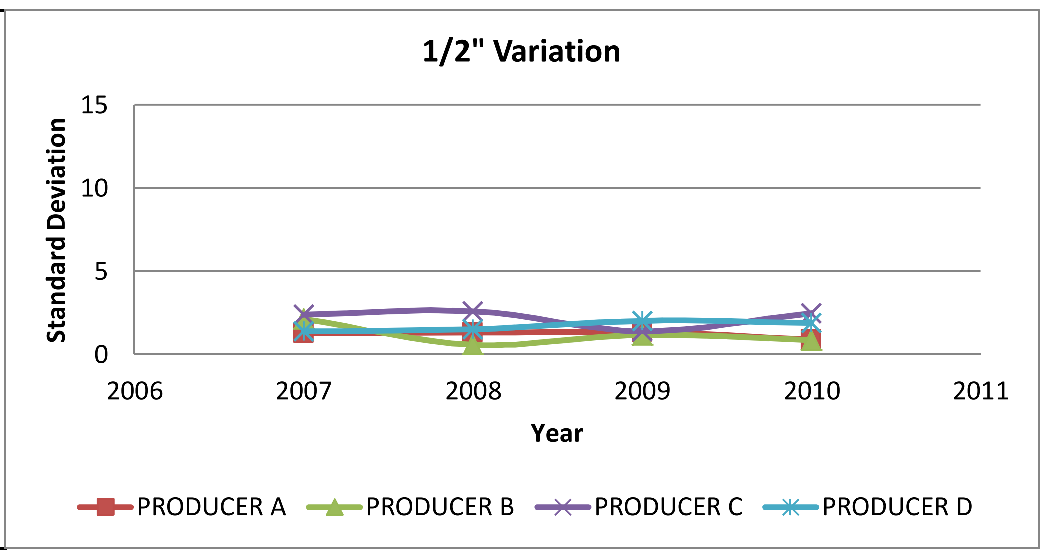
#4 - Percent Passing #4 Sieve



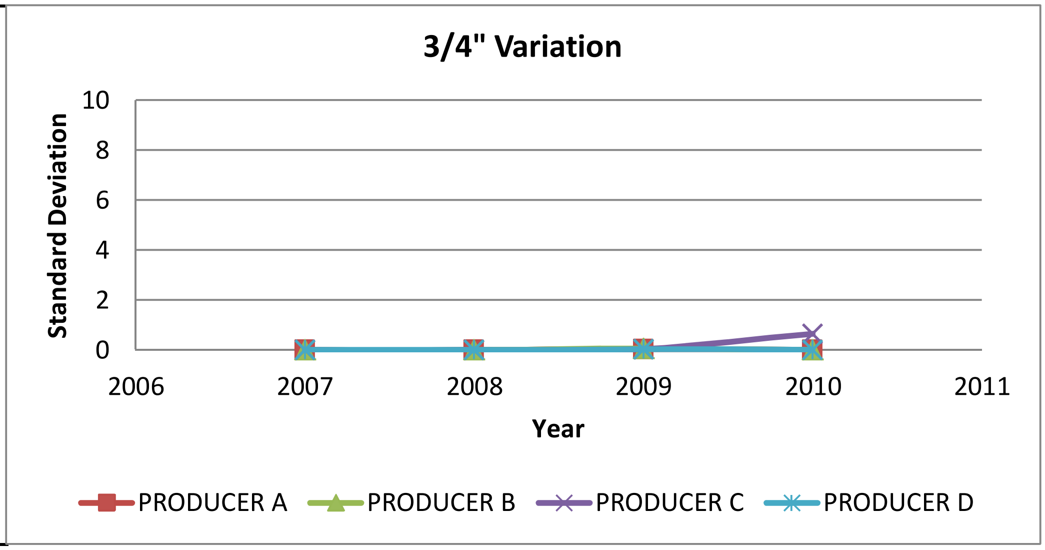
3/8" - Percent Passing 3/8" Sieve



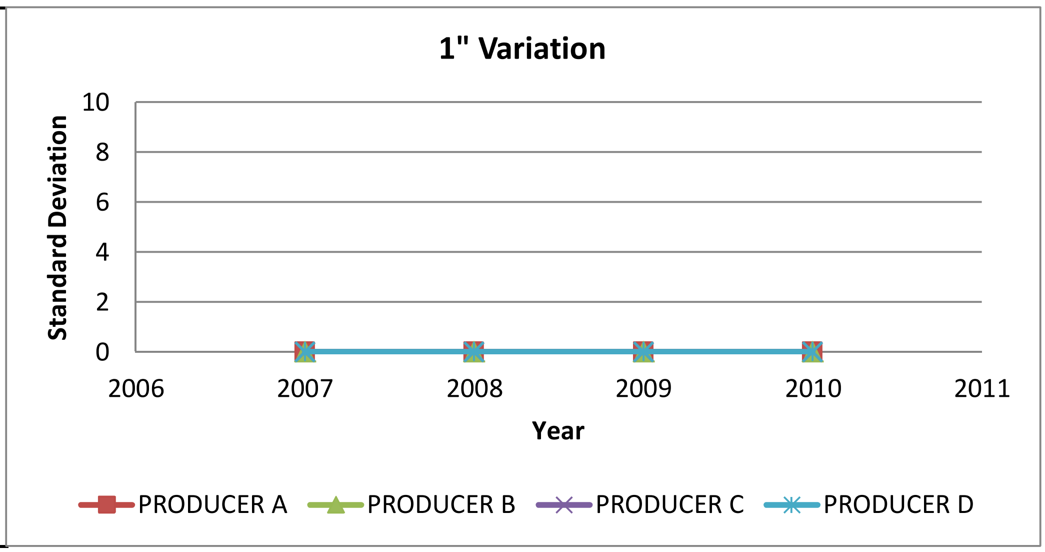
1/2" - Percent Passing 1/2" Sieve



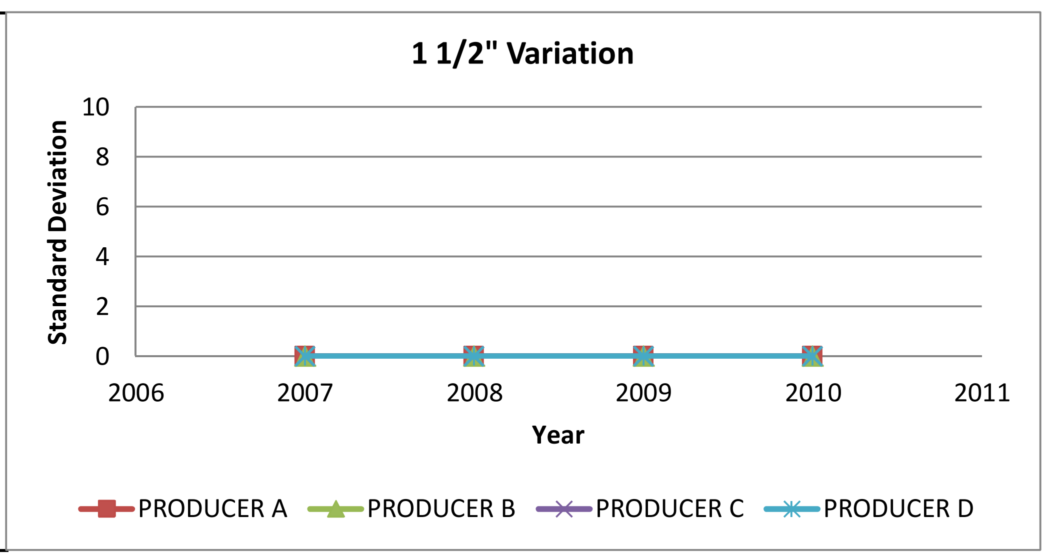
3/4" - Percent Passing 3/4" Sieve



1" - Percent Passing 1" Sieve



1 1/2" - Percent Passing 1 1/2" Sieve



2" - Percent Passing 2" Sieve