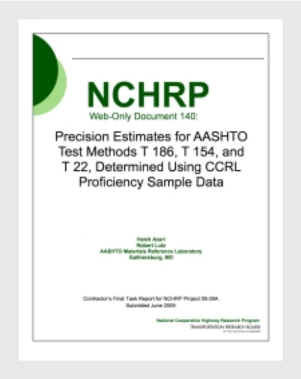
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Precision Estimates for AASHTO Test Methods T 186, T 154, and T 22, Determined Using CCRL Proficiency Sample Data

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TABLE OF CONTENT

LIST OF TABLES

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CHAPTER 1. INTRODUCTION AND RESEARCH APPROACH

1.1 INTRODUCTION

Under National Cooperative Highway Research Programs (NCHRP) Project 9-26, the AASHTO Materials Reference Laboratory (AMRL) is conducting a multi-phase research project to improve estimates of precision in AASHTO test methods for various highway construction materials. The report from Phase 1 of Project 9-26 includes precision estimates of selected volumetric properties of HMA using non-absorptive aggregates [1]. The report from Phase 2 discusses the results of an investigation into the cause of variations in HMA bulk specific gravity test results using non-absorptive aggregates [2]. The report from Phase 3 includes a robust technique developed by AMRL for analyzing proficiency sample data for the purpose of obtaining reliable single-operator and multilaboratory estimates of precision [3]. The report from phase 4 includes two parts, part one covers the precision estimates of selected volumetric properties of HMA using absorptive aggregates and part two investigates the effect of aging period on volumetric properties of the mixtures with absorptive aggregates [4]. The report from Phase 5 includes update of precision estimates for AASHTO Standard Test Method T 269 [5].

This report includes the results of Part 2 of 3 in Task 1 of NCHRP 9-26A where data from the CCRL Proficiency Sample Program (PSP) are used to update precision estimates for AASHTO Standard Test Method T 186 “Early Stiffening of Hydraulic Cement (Paste Method)” [6], T 154 “Time of Setting of Hydraulic Cement Paste by Gillmore Needles” [7], and T 22 “Compressive Strength of Cylindrical Concrete Specimens” [8].

Data used in this study are the physical properties of hydraulic cement paste samples and compressive properties of hydraulic cement concrete samples that were sent to the laboratories participating in the CCRL Proficiency Program. The laboratories receive annual or biannual shipments of CCRL paired proficiency samples, which are tested according to the specified ASTM test methods [9]. The physical components that were tested and are used in this study include early stiffening of hydraulic cement (% false set) and the time of initial and final setting of hydraulic cement. The compressive properties that were tested and are used in this study include 7-day compressive strength of hydraulic cement concrete. The hydraulic cement paste samples for the physical analysis were prepared and tested according to the methods explained in ASTM C 451 [10] “Early Stiffening of Hydraulic Cement (Paste Method)” and C 266 “Time of Setting of Hydraulic-Cement Paste by Gillmore Needles” [11], which are the same as AASHTO T 186 and T 154, respectively. The hydraulic cement concrete samples for the compressive property analysis were prepared and tested according to ASTM C 39 [12] that is equivalent to AASHTO T 22.

The technique developed by AMRL in Phase 3 of NCHRP 9-26 project was utilized for analyzing proficiency sample data. This technique is a four step methodology for shaving off extraneous results and analyzing the core data of a paired data set. The results of the analysis of the “core data” can then be used to obtain reliable single-operator and multilaboratory estimates of precision.

The precision estimates for physical properties of hydraulic cement in this study resulted from analysis of 18 data sets of 3 physical properties of CCRL proficiency samples. The precision statement for the compressive strength of hydraulic cement concrete resulted from analysis of 6 data sets of CCRL paired proficiency samples. Only the most recent proficiency samples were used in order to account for changes in test precision resulting from recent improvements in the test methods.

1.1.1 Problem Statement

AASHTO Standard Test Methods applicable to highway materials require periodic studies to determine estimates of precision. Some precision estimates become outdated as a result of improvements in the methods while other estimates need to be verified to see if they are still accurate. While some methods need to be expanded to take into account a wider range of materials other newer test methods may not have precision estimates of any kind. The AASHTO test methods T 186, T 154, and T 22 have been revised recently; however, the existing precision estimates do not reflect the latest improvements to the test methods.

1.1.2 Research Objective

The objective of this study as part of task 1 of NCHRP 9-26A study is to update single-operator and multilaboratory precision estimates for the AASHTO T 186 “Early Stiffening of Hydraulic Cement (Paste Method)”, T 154 “Time of Setting of Hydraulic Cement Paste by Gillmore Needles”, and T 22 “Compressive Strength of Cylindrical Concrete Specimens” based on the most recent version of the test methods.

1.2 SCOPE OF STUDY

This work is limited to an evaluation of 24 sets of data collected from laboratories participating in the physical analysis of hydraulic cement paste and compressive properties of hydraulic cement concrete of the CCRL Proficiency Sample Program. The data used will reflect a wide range of test values and cement types, which are included in the scope of the CCRL Proficiency Sample Program.

1.3 PROFICIENCY SAMPLES USED IN STUDY

Included in the study are the most recent CCRL hydraulic cement and hydraulic concrete proficiency samples that were tested according to ASTM C 451 (AASHTO T 186) “Early Stiffening of Hydraulic Cement (Paste Method)”, ASTM C 266 (AASHTO T 154) “Time of Setting of Hydraulic Cement Paste by Gillmore Needles”, and ASTM C 39 (AASHTO T22) “Compressive Strength of Cylindrical Concrete Specimens.” The cement types used for the cement pastes in the study are type I, type I with limestone, type I/II, type I/II with limestone, and type V with limestone. The concrete samples included in the study are one set of paired 4 in. x 8 in. cylinder and five sets of paired 6 in. x 12 in cylinder. Table 1-1 provides the sample designation of the CCRL cement pastes and the date of the final report on the analysis of the sample properties. Table 1-2 provides the sample designation of the CCRL hydraulic cement concrete and the date of the final report on the analysis of the sample properties.

Table 1-1- Sample Designation, Cement Type, and Date of Final Reports of Proficiency Samples used for AASHTO T 186 (ASTM C 451) and AASHTO T 154 (C 266) Data Mining

Sample Designation	Cement Type	Date of Final Report
147 & 148	Type I/II	March 2003
149 & 150	Type I	September 2003
153 & 154	Type I	October 2004
155 & 156	Type I	April 2005
157 & 158	Type V w/ limestone (157) Type & I/II w/ limestone (158)	October 2005
159 & 160	Type I w/ limestone (159) & Type I/II w/ limestone (160)	April 2006
161 & 162	Type I (161) & Type I w/ limestone (162)	October 2006

Table 1-2- Sample Designation, Sample Size, and Date of Final Report of Proficiency Samples used for AASHTO T 22 (ASTM C 39) Data Mining

Sample Designation	Sample Size Diameter (in.) x Height (in.)	Date of Final Report
127 & 128	4 x 8	June-03
135 & 136	6 x 12	July-05
137 & 138	6 x 12	February-06
139 & 140	6 x 12	June-06
141 & 142	6 x 12	January-07
143 & 144	6 x 12	June-07

CHAPTER 2. RESULTS OF ANALYSIS AND ESTIMATES OF PRECISION

2.1 TEST DATA

The test data in this study are the physical properties of hydraulic cement paste and compressive properties of hydraulic cement concrete. The T 186 (C 451) data are the early stiffening of hydraulic cement paste in percentages, the T 154 (C 266) data are the time of initial and final setting of hydraulic cement paste in minutes, and the T 22 (C 39) test data are the compressive strength of hydraulic cement concrete in pound per square inch (psi). The individual results for each of the 24 proficiency data sets used to create precision estimates can be found in Appendices A to D. This chapter includes summaries of the data and the resulting precision estimates.

2.2 ANALYSIS OF THE DATA

2.2.1 Early Stiffening (False Set), T 186

The percentages of early stiffening of hydraulic Cement (paste method) were analyzed for each of the 6 proficiency sample pairs included in this study. Table 2-1 displays the results of the analyses. Precision estimates are based, where appropriate, on either the coefficients of variation (CV%) or the pooled standard deviation (1s) values. The results from analyzing the data for percent early stiffening for hydraulic cement paste are found in Appendix A.

Table 2-1- Summary Table for % Early Stiffening of Hydraulic Cement, T 186

Sample Number	No. of Labs	Average Results		Repeatability			Reproducibility		Reproducibility	
		Odd Samples	Even Samples	1s	Odd Samples	Even Samples	Odd Samples	Odd Samples	Even Samples	Even Samples
					CV%	CV%	1s	CV%	1s	CV%
147 & 148	171	77	82	6.8	8.7	8.2	7.4	9.6	7.8	9.5
149 & 150	186	69	79	7.6	11	9.6	9.2	13.3	8.6	10.9
153 & 154	198	75	76	8.5	11.4	11.2	9.1	12.2	10.2	13.4
155 & 156	210	83	69	9.3	11.2	13.4	7.4	8.9	11.7	17
159 & 160	201	85	83	4.8	5.6	5.7	6.2	7.3	6.4	7.7
161 & 162	189	84	79	5.4	6.4	6.8	6	7.1	7	8.8

A review of the data shown in Table 2-1 indicates that there is no trend between averages and standard deviations of the % early stiffening measurements; therefore, form of the precision estimates should be based on the sample standard deviation. The pooled repeatability sample standard deviation for the 6 pairs of samples analyzed is 7.29 percent. The corresponding pooled reproducibility sample standard deviation is 8.30 percent. The pooled estimates are derived using the following equation from Ku [11]:

$$s_p = \sqrt{\frac{(n_1 - 1)s_1^2 + (n_2 - 1)s_2^2 + \ldots + (n_k - 1)s_k^2}{n_1 + n_2 + \ldots + n_k - k}} \quad \text{(Equation 1)}$$

Where:

s_p = pooled standard deviation

s_k = kth standard deviation

n_k = number of laboratories analyzed resulting in kth standard deviation

2.2.2 Gillmore Time of Setting, T 154

2.2.2.1 Initial Time of Setting

The Gillmore initial time of setting of hydraulic cement were analyzed for each of the 6 cement paste proficiency sample pairs tested in this study. Table 2-2 displays the results of the analyses. Precision estimates are based, where appropriate, on either the coefficients of variation (CV%) or the pooled standard deviation (1s) values. The results from analyzing the data for initial time of setting of hydraulic cement paste are found in Appendix B.

Table 2-2- Summary Table for Initial Time of Setting, T 154

Sample Number	No. of Labs	Average Results		Repeatability			Reproducibility		Reproducibility	
		Odd Samples	Even Samples	1s	Odd Samples CV%	Even Samples CV%	Odd Samples 1s	Odd Samples CV%	Even Samples 1s	Even Samples CV%
147 & 148	160	139	175	13.2	9.5	7.6	21.4	15.5	19.0	10.9
149 & 150	164	153	165	11.0	7.2	6.7	20.4	13.3	21.2	12.9
153 & 154	168	193	173	14.0	7.3	8.1	28.6	14.8	25.5	14.8
157 & 158	165	185	160	12.6	6.8	7.9	24.2	13.1	21.6	13.5
159 & 160	161	159	154	9.6	6.0	6.2	20.6	12.9	21.5	13.9
161 & 162	156	160	178	10.0	6.2	5.6	19.4	12.1	22.3	12.5

A review of the data shown in Table 2-2 indicates that there is no trend between averages and standard deviations of the initial time of setting; therefore, the form of the precision estimates should be based on the sample standard deviation. The pooled repeatability sample standard deviation of the 6 pairs of samples analyzed is 11.9 minutes. The corresponding pooled reproducibility sample standard deviation is 22.5 minutes. The pooled estimates are derived using Equation 1.

2.2.2.2 Final Time of Setting

The Gillmore final time of setting of hydraulic cement were analyzed for each of the 6 cement paste proficiency sample pairs tested in this study. Table 2-3 displays the results of the analyses. Precision estimates are based, where appropriate, on either the coefficients of variation (CV%) or the pooled standard deviation (1s) values. The results from analyzing the final time of setting of cement paste are found in Appendix C.

Table 2-3- Summary Table for Final Time of Setting, T 154

Sample Number	No. of Labs	Average Results		Repeatability			Reproducibility		Reproducibility	
		Odd Samples	Even Samples	1s	Odd Samples CV%	Even Samples CV%	Odd Samples 1s	Odd Samples CV%	Even Samples 1s	Even Samples CV%
147 & 148	164	238	281	18.6	7.8	6.6	35.4	14.9	35.6	12.7
149 & 150	166	258	265	16.0	6.2	6.0	35.0	13.5	36.1	13.6
153 & 154	166	303	278	18.3	6.0	6.6	41.8	13.8	38.1	13.7
157 & 158	168	299	269	16.9	5.7	6.3	40.2	13.4	36.7	13.7
159 & 160	167	267	260	12.4	4.6	4.8	36.4	13.6	37.5	14.4
161 & 162	160	260	282	14.4	5.5	5.1	31.8	12.3	33.1	11.8

A review of the data shown in Table 2-3 indicates that there is no trend between averages and standard deviations of the final time of setting; therefore, that the form of the precision estimates should be based on the sample standard deviation. The pooled repeatability sample standard deviation of the six pairs of samples analyzed is 16.1 minutes. The corresponding pooled reproducibility sample standard deviation is 36.5 minutes. The pooled estimates are derived using Equation 1.

2.2.3 Compressive Strength, T 22

The 7-day compressive strength of hydraulic cement concrete were analyzed for one set of 4 in. x 8 in. and five sets of 6 in. x 12 in. proficiency sample pairs tested in this study. Table 2-4 displays the results of the analyses. Precision estimates are based, where appropriate, on either the coefficients of variation (CV%) or the pooled standard deviation (1s) values. The results from analyzing the compressive strength of hydraulic cement concrete are found in Appendix D.

Table 2-4- Summary Table for 7-Day Compressive Strength, T 22

Sample Number	No. of Labs	Average Results		Repeatability			Reproducibility		Reproducibility	
		Odd Samples	Even Samples	1s	Odd Samples CV%	Even Samples CV%	Odd Samples 1s	Odd Samples CV%	Even Samples 1s	Even Samples CV%
127 & 128	267	3945	3952	168.5	4.3	4.3	281.7	7.1	321.5	8.1
135 & 136	910	3851	3970	181.9	4.7	4.6	314.4	8.2	321.7	8.1
137 & 138	935	4596	4601	228.5	5.0	5.0	394.5	8.6	357.4	7.8
139 & 140	979	4812	4526	212.5	4.4	4.7	369.0	7.7	352.5	7.8
141 & 142	1002	4173	4334	191.5	4.6	4.4	342.8	8.2	382.5	8.8
143 & 144	994	4042	4484	197.4	4.9	4.4	346.2	8.6	340.2	7.6

A review of the data shown in Table 2-4 indicates that there is a clear trend between averages and standard deviations of compressive strength measurements; therefore, the form of the precision estimates should be based on sample coefficient of variation. The average repeatability sample coefficient of variation for the 6 in. x 12 in. samples analyzed is 4.7%. The corresponding average reproducibility sample coefficient of variation is 8.1%. The average repeatability sample coefficient of variation for the 4 in. x 8 in. samples analyzed is 4.3%. The corresponding average reproducibility sample standard deviation is 7.6%.

2.3 COMPARISON OF CURRENT AND DEVELOPED PRECISONS

2.3.1 Early Stiffening (False Set), T 186

The precision estimates developed in this study were compared with the existing precisions for AASHTO T 186. Table 2-5 shows the new and existing precisions. As indicated from the table, both repeatability and reproducibility statistics has improved due to the recent improvements in the test method.

Table 2-5- Comparison of the Proposed and Existing Precision Estimates for T 186

Condition of Test and Type Index	Standard Deviation, 1s (%)		Acceptable Range of Two Test Results, d2s (%)	
	New	Existing	New	Existing
Single-Operator Precision:	7	10	21	28
Multilaboratory Precision:	8	12	24	34

2.3.2 Gillmore Time of Setting, T 154

The precision estimates of T 154 developed in this study were compared with the existing precisions for the test method. Table 2-6 shows the new and existing precisions. As indicated from the table, both repeatability and reproducibility statistics has improved due to the recent improvements in the test method.

Table 2-6- Comparison of Proposed and Existing Precision Estimates for T 154

Condition of Test and Type Index	Standard Deviation (minutes), 1s		Acceptable Range of Two Test Results (minutes), d2s	
	New	Existing	New	Existing
Single-Operator Precision:				
Initial Time of Setting	12	16	34	44
Final Time of Setting	16	22	46	62
Multilaboratory Precision:				
Initial Time of Setting	22	28	63	78
Final Time of Setting	37	46	104	129

2.3.3 Compressive Strength, T 22

The precision estimates of T 22 developed in this study were compared with the existing precisions for the test method. Table 2-7 provides the proposed and existing precisions. As indicated from the table, the new repeatability and reproducibility standard deviations are larger than the existing precisions. It is not clear if this difference is due to change in the CCRL reference material or the change in the method of testing.

Table 2-7-Comparison of the Proposed and Existing Precision Estimates for T 22

Condition of Test and Type Index	Coefficient of Variation (percent of mean)		Acceptable Range of Two Test Results (percent of mean)	
	New	Existing	New	Existing
Single-Operator Precision:				
6 by 12 in. [150 by 300 mm]	4.7	2.4	13.1	6.6
4 by 8 in. [100 by 200 mm]	4.3	3.2	12.0	9.0
Multilaboratory Precision:				
6 by 12 in. [150 by 300 mm]	8.1	5.0	22.8	14.0
4 by 8 in. [100 by 200 mm]	7.6	NA	21.4	NA

CHAPTER 3. CONCLUSIONS AND RECOMMENDATIONS

3.1 COMMENTARY

This study was conducted to prepare precision estimates for AASHTO Standard Test Methods T 186 "Early Stiffening of Hydraulic Cement (Paste Method)", T 154 "Time of Setting of Hydraulic Cement Paste by Gillmore Needles", and T 22 "Compressive Strength of Cylindrical Concrete Specimens". The CCRL proficiency data analyzed in this study are more up to date than the data used for the current estimate of precision and reflect a wide range of cement types and test values. In all cases the data set used to derive the precision estimate included well over 160 laboratories.

3.2 CONCLUSION

Using the most recent sets of CCRL proficiency sample data for T 186, T 154, and T 22, precision estimates of the test methods were recomputed. There were 6 sets of paired data for each T 186 and T 22 test methods and 6 sets of data for each initial and final time of setting of T 154 test method. The comparison of the developed precision estimates with the exiting precisions indicated that with using the new sets of data both repeatability and reproducibility standard deviations of T 186 and T 154 have improved; however, both the repeatability and reproducibility coefficient of variations of T 22 have increased significantly. It is not clear if the increase in test variability is due to the change in the material, e.g., cement type, or the change in test method.

3.3 RECOMMENDATIONS

It is recommended that the precision and bias statements in Sections 3.4, 3.5, and 3.6 be adopted for T 186, T 154, and T 22 test methods, respectively. The proposed precisions would reflect the variability associated with the mostly used hydraulic cement and the most recent versions of the test methods.

3.4 PRECISION STATEMENT FOR AASHTO T 186 EARLY STIFFENING OF HYDRAULIC CEMENT (PASTE METHOD)

X. Precision and Bias

X.1 Precision - Criteria for judging the acceptability of Gillmore initial and final time of setting obtained by T 186 test method are given in Table X:

Note: the figures given in Column 2 are the standard deviations that have been found to be appropriate for the materials and conditions of test described in Column 1. The figures in Column 3 are the limits that should not be exceeded by the difference between the results of two properly conducted tests.

Table X – Precision Estimates of Early Stiffening of Hydraulic Cement (Paste Method)

Condition of Test and Test Property	Standard Deviation (1s), Percent[a]	Acceptable Range of Two Test Results (d2s), Percent[a]
Single Operator Precision:	7	21
Multilaboratory Precision:	8	24

[a] These values represent the 1s and d2s limits described in ASTM Practice C670.

Note – The precision estimates given in Table X are based on the analysis of test results from 6 pairs of CCRL proficiency samples. The data analyzed consisted of results from 171 to 210 laboratories for each of the pairs of samples. The analysis included cement pastes with average False Set of 69% to 85%.

X.2 Bias – No information can be presented on the bias of the procedure because no comparison with the material having an accepted reference value was conducted.

3.5 PRECISION STATEMENT FOR AASHTO T 154 TIME OF SETTING OF HYDRAULIC CEMENT PASTE BY GILLMORE NEEDLES

X. Precision and Bias

X.1 Precision - Criteria for judging the acceptability of Gillmore initial and final time of setting obtained by T 154 test method are given in Table X:

Note: the figures given in Column 2 are the standard deviations that have been found to be appropriate for the materials and conditions of test described in Column 1. The figures in Column 3 are the limits that should not be exceeded by the difference between the results of two properly conducted tests.

Table X – Precision Estimates of Time of Setting of Hydraulic-Cement Paste by Gillmore Needles

Condition of Test and Test Property	Standard Deviation (minutes) 1s[a]	Acceptable Range of Two Test Results (minutes) d2s[a]
Single-Operator Precision:		
Initial Time of Setting	12	34
Final Time of setting	16	46
Multilaboratory Precision:		
Initial Time of Setting	23	64
Final Time of setting	37	103

[a] These values represent the 1s and d2s limits described in ASTM Practice C670.

Note – The precision estimates given in Table X are based on the analysis of test results from 6 pairs of CCRL proficiency samples. The data analyzed consisted of results from 156 to 168 laboratories for each of the pairs of samples. The analysis included cement pastes with the average Gillmore Initial Time of Setting of 139 to 193 minutes and average Gillmore Final Time of Setting of 238 to 303 minutes.

X.2 Bias – No information can be presented on the bias of the procedure because no comparison with the material having an accepted reference value was conducted.

3.6 PRECISION STATEMENT FOR AASHTO T 22 COMPRESSIVE STRENGTH OF CYLINDRICAL CONCRETE SPECIMENS

X. Precision and Bias

X.1 Precision - Criteria for judging the acceptability of Gillmore initial and final time of setting obtained by T 22 test method are given in Table X:

Note: the figures given in Column 2 are the standard deviations that have been found to be appropriate for the materials and conditions of test described in Column 1. The figures in Column 3 are the limits that should not be exceeded by the difference between the results of two properly conducted tests.

Table X – Precision Estimates of Compressive Strength of Cylindrical Concrete Specimens

Condition of Test and Test Property	Coefficient of Variation 1s, Percent of Average[a]	Acceptable Range of Two Test Results d2s, Percent of Average[a]
Single-Operator Precision:		
6 by 12 in.[150 by 300 mm]	4.7	13.2
4 by 8 in.[100 by 200 mm]	4.3	12.1
Multilaboratory Precision:		
6 by 12 in.[150 by 300 mm]	8.1	23.0
4 by 8 in.[100 by 200 mm]	7.6	21.6

[a] These values represent the 1s and d2s limits described in ASTM Practice C670.

Note – The precision estimates given in Table X are based on the analysis of test results from one pair of 4 in. by 8 in. and five pairs of 6 in. by 12 in. CCRL hydraulic concrete proficiency samples. The data analyzed consisted of results from 267 laboratories for the 4 in. by 8 in. samples and 910 to 1002 laboratories for each of the 6 in. by 12 in. pairs of samples. The analysis included 4 in. by 8 in samples with the average compressive strength of 3950 psi and 6 in. by 12 in. samples with the average compressive strength of 3851 psi to 4812 psi.

X.2 Bias – No information can be presented on the bias of the procedure because no comparison with the material having an accepted reference value was conducted.

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[12] ASTM, Designation C 39, "Compressive Strength of Cylindrical Concrete Specimens," Annual Book of ASTM Standards, Volume 04.02, ASTM, West Conshohocken, PA, 2006.

[13] Ku, Harry H., "Statistical Concepts in Metrology," NIST Special Publication 300, Volume 1, 1969: p 316-40.

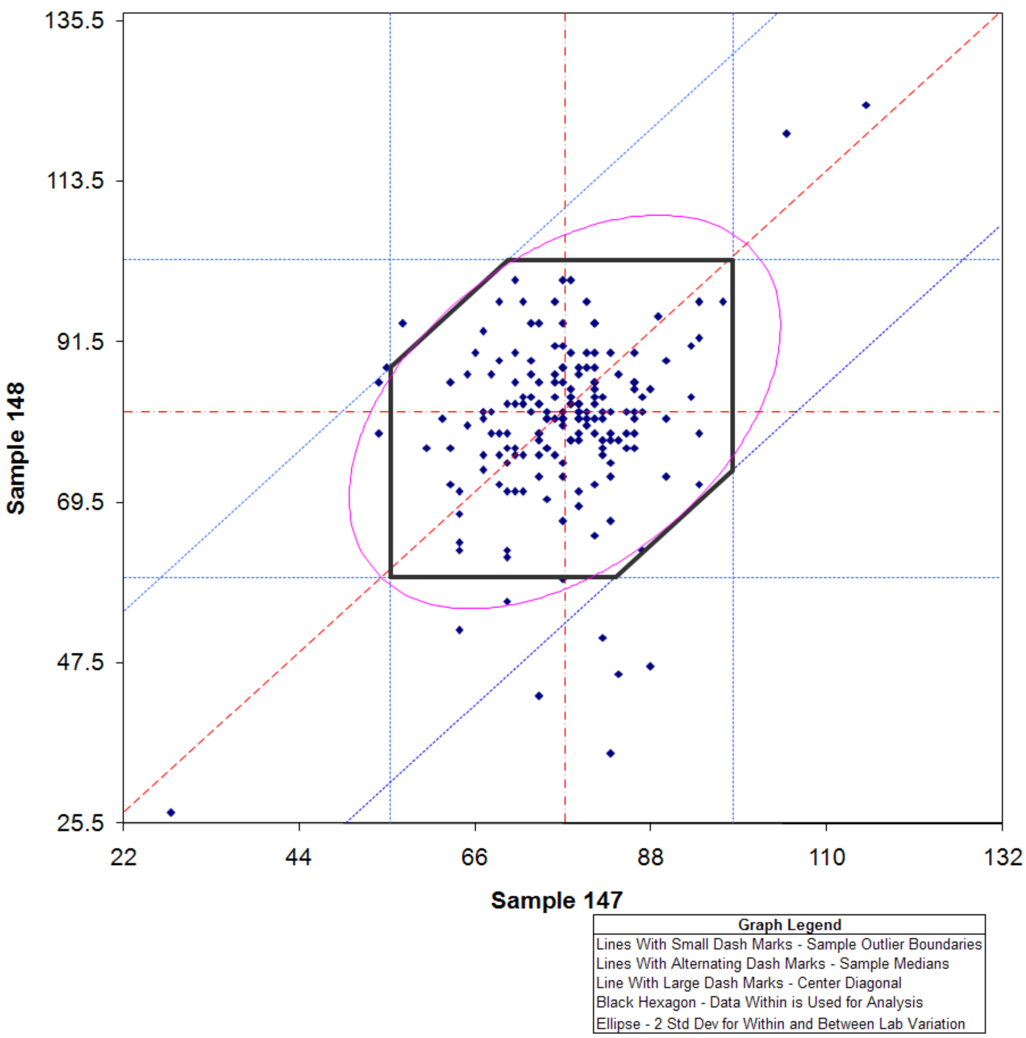
APPENDIX A: EARLY STIFFENING (FALSE SET)

Graph and Analysis Results for AASHTO T 186

Early Stiffening of Hydraulic Cement (Paste Method)

CCRL Samples 147 and 148

Test Property: Early stiffening (False Set), %



Source of Data: AASHTO Materials Reference Laboratory Proficiency Sample Program
CCRL Samples 147 and 148
Final Report Issued March 2003

Participation:

192	Total Laboratories
9	Laboratories Determined to be Invalid
12	Laboratories Determined to be Outliers
171	Total Laboratorires Included in Analysis

Average Results	
Sample 147 Average	Sample 148 Average
77	82

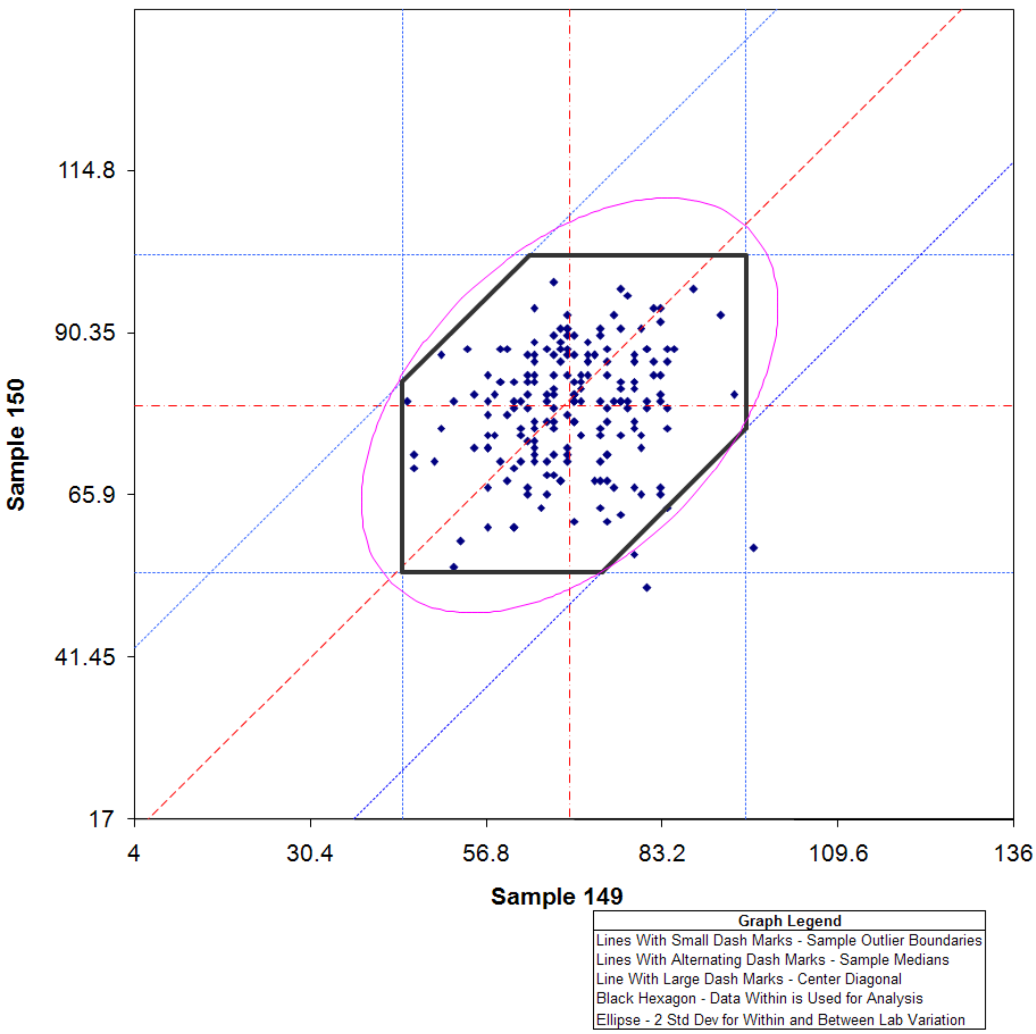
Repeatability			
1s	d2s	CV% (147)	CV% (148)
6.8	19.1	8.7	8.2

Reproducability (Sample 147)		
1s	d2s	CV%
7.4	21.0	9.6

Reproducability (Sample 148)		
1s	d2s	CV%
7.8	22.1	9.5

Graph and Analysis Results for AASHTO T 186
Early Stiffening of Hydraulic Cement (Paste Method)
CCRL Samples 149 and 150

Test Property: Early stiffening (False Set), %



Source of Data: AASHTO Materials Reference Laboratory Proficiency Sample Program
CCRL Samples 149 and 150
Final Report Issued September 2003

Participation:

190	Total Laboratories
0	Laboratories Determined to be Invalid
4	Laboratories Determined to be Outliers
186	Total Laboratorires Included in Analysis

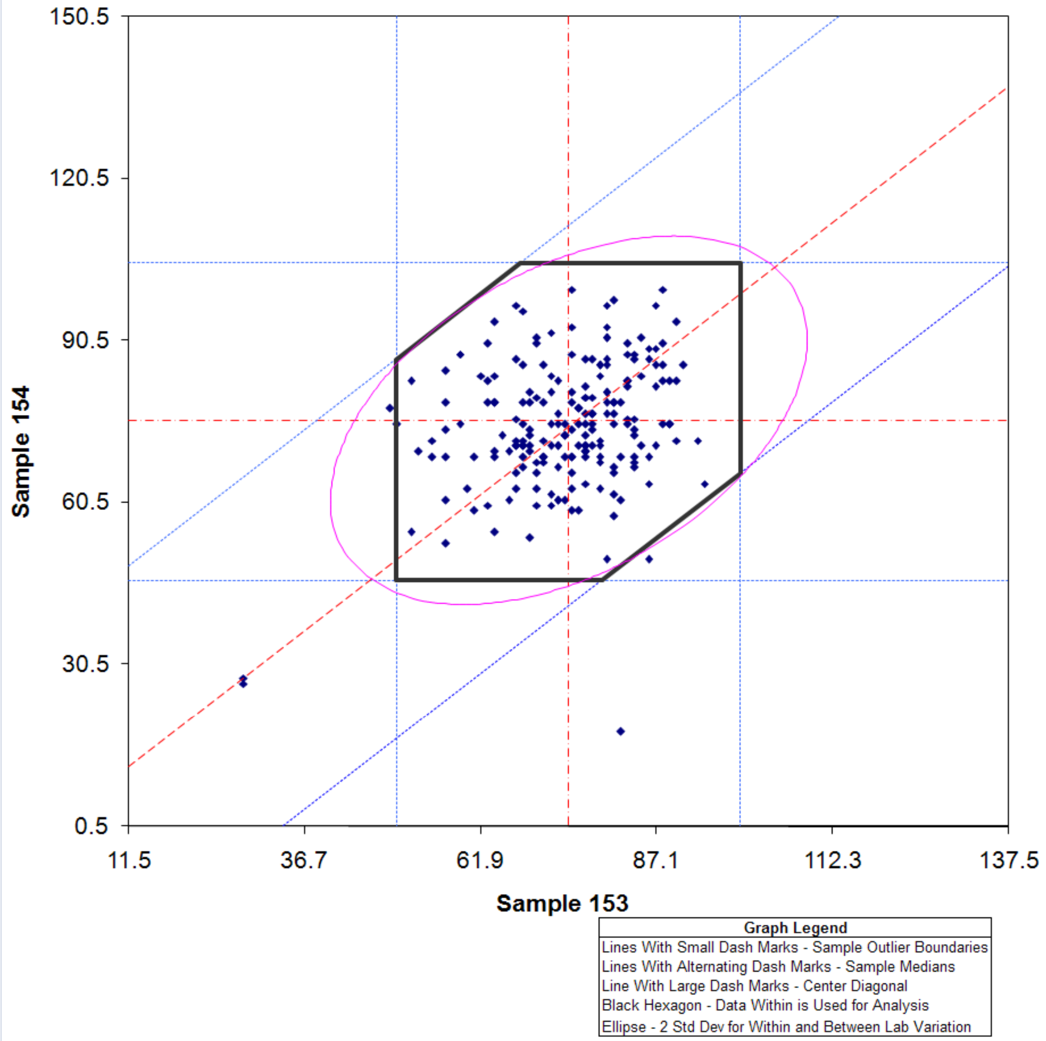
Average Results	
Sample 149 Average	Sample 150 Average
69	79

Repeatability			
1s	d2s	CV% (149)	CV% (150)
7.6	21.5	11.0	9.6

Reproducibility (Sample 149)		
1s	d2s	CV%
9.2	26.1	13.3

Reproducibility (Sample 150)		
1s	d2s	CV%
8.6	24.4	10.9

Graph and Analysis Results for AASHTO T 186
Early Stiffening of Hydraulic Cement (Paste Method)
CCRL Samples 153 and 154
Test Property: Early stiffening (False Set), %



Source of Data: AASHTO Materials Reference Laboratory Proficiency Sample Program
CCRL Samples 153 and 154
Final Report Issued October 2004

Participation:

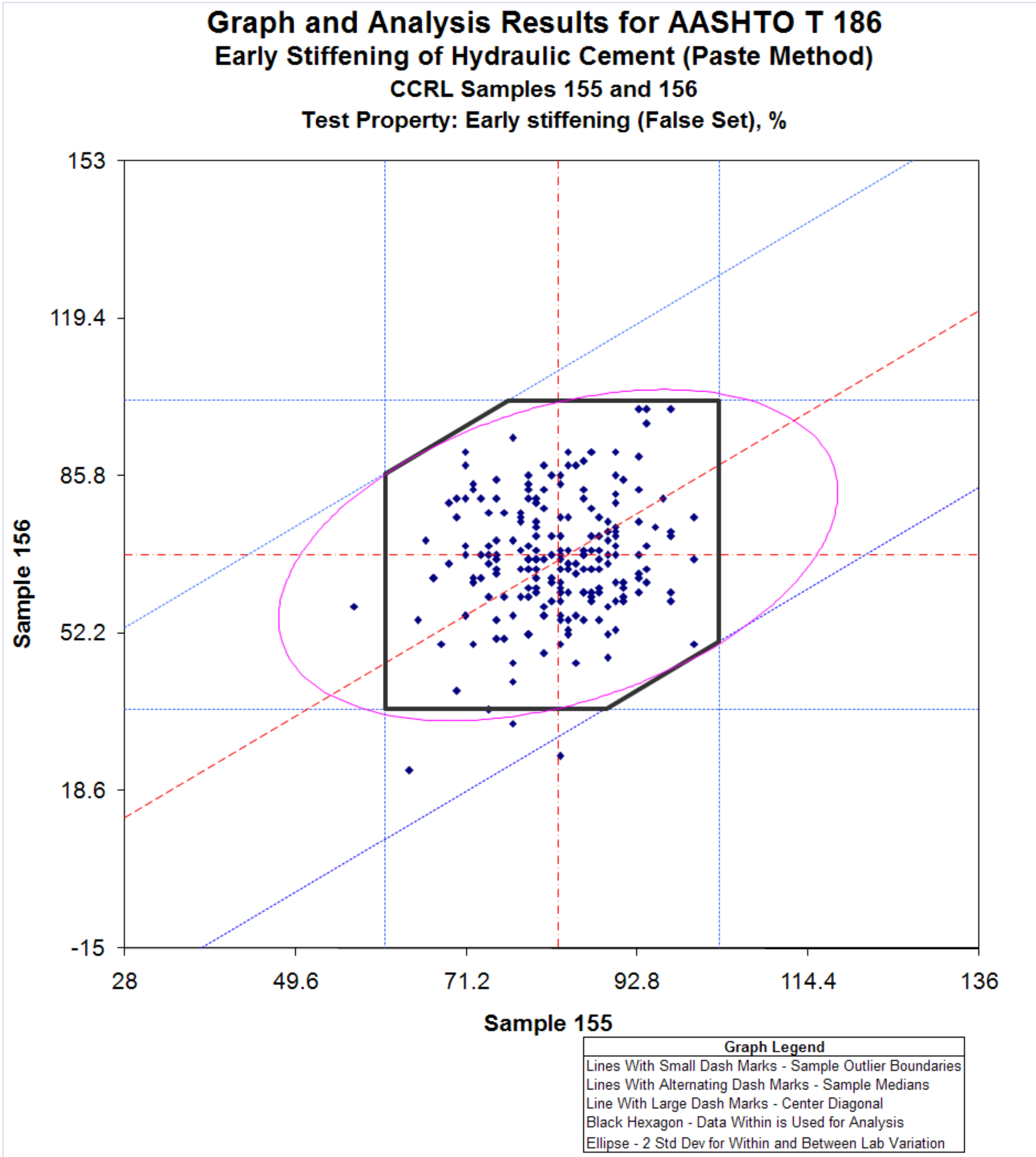
203	Total Laboratories
3	Laboratories Determined to be Invalid
2	Laboratories Determined to be Outliers
198	Total Laboratorires Included in Analysis

Average Results	
Sample 153 Average	Sample 154 Average
75	76

Repeatability			
1s	d2s	CV% (153)	CV% (154)
8.5	24.1	11.4	11.2

Reproducability (Sample 153)		
1s	d2s	CV%
9.1	25.8	12.2

Reproducability (Sample 154)		
1s	d2s	CV%
10.2	28.8	13.4



Source of Data: AASHTO Materials Reference Laboratory Proficiency Sample Program
CCRL Samples 155 and 156
Final Report Issued April 2005

Participation:

216	Total Laboratories
1	Laboratories Determined to be Invalid
5	Laboratories Determined to be Outliers
210	Total Laboratorires Included in Analysis

Average Results	
Sample 155 Average	Sample 156 Average
83	69

Repeatability			
1s	d2s	CV% (155)	CV% (156)
9.3	26.2	11.2	13.4

Reproducability (Sample 155)		
1s	d2s	CV%
7.4	20.9	8.9

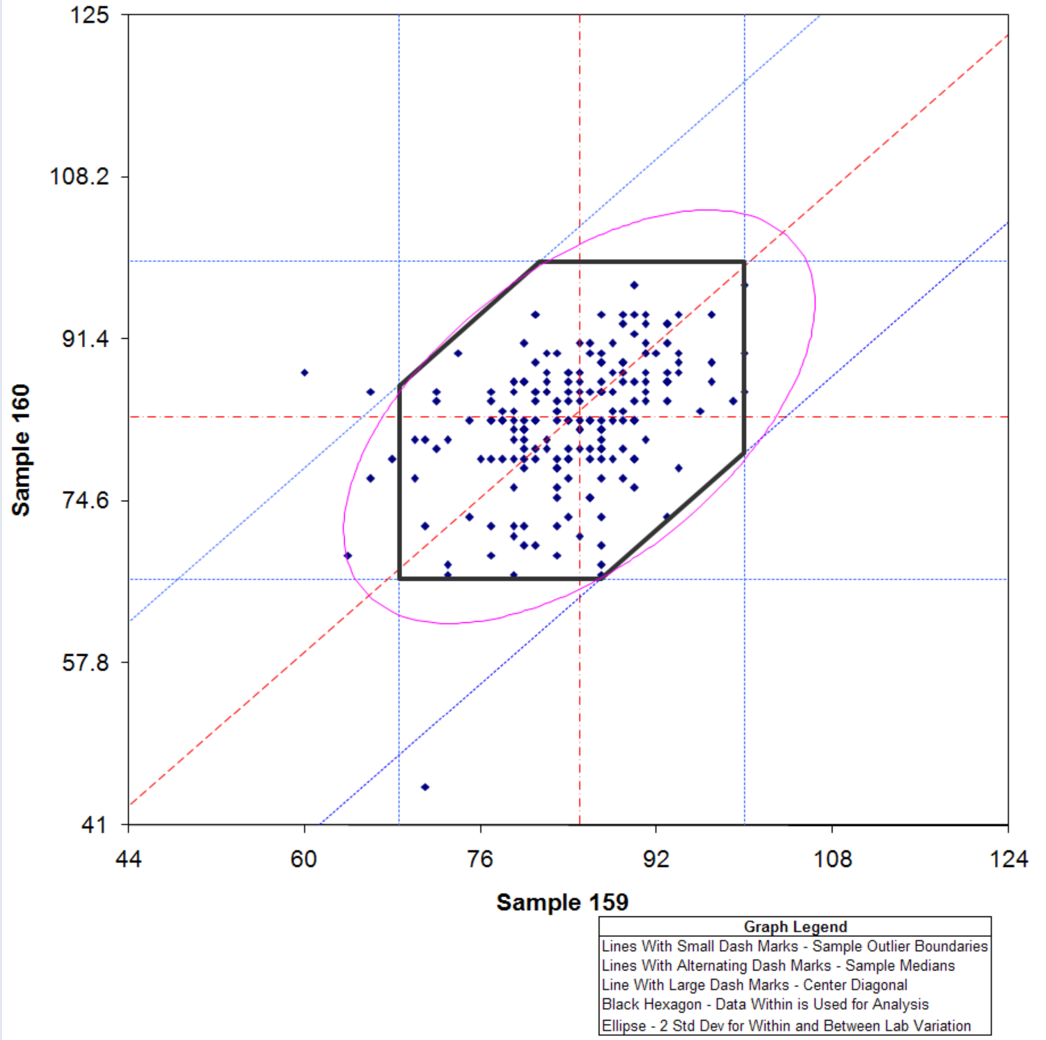
Reproducability (Sample 156)		
1s	d2s	CV%
11.7	33.1	17.0

Graph and Analysis Results for AASHTO T 186

Early Stiffening of Hydraulic Cement (Paste Method)

CCRL Samples 159 and 160

Test Property: Early stiffening (False Set), %



Source of Data: AASHTO Materials Reference Laboratory Proficiency Sample Program
CCRL Samples 159 and 160
Final Report Issued April 2006

Participation:

207	Total Laboratories
1	Laboratories Determined to be Invalid
5	Laboratories Determined to be Outliers
201	Total Laboratorires Included in Analysis

Average Results	
Sample 159 Average	Sample 160 Average
85	83

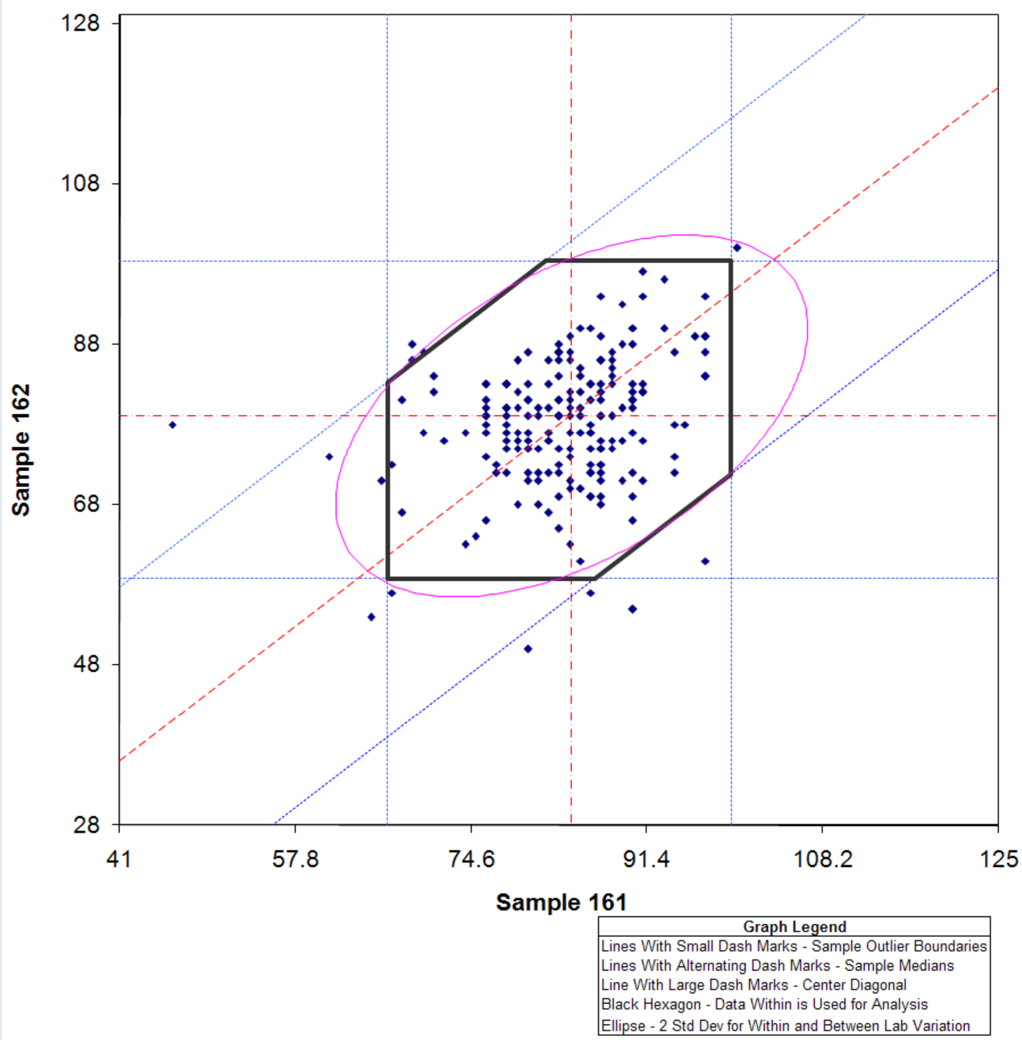
Repeatability			
1s	d2s	CV% (159)	CV% (160)
4.8	13.5	5.6	5.7

Reproducibility (Sample 159)		
1s	d2s	CV%
6.2	17.5	7.3

Reproducibility (Sample 160)		
1s	d2s	CV%
6.4	18.1	7.7

Graph and Analysis Results for AASHTO T 186
Early Stiffening of Hydraulic Cement (Paste Method)
CCRL Samples 161 and 162

Test Property: Early stiffening (False Set), %



Source of Data: AASHTO Materials Reference Laboratory Proficiency Sample Program
CCRL Samples 161 and 162
Final Report Issued October 2006

Participation:

203	Total Laboratories
1	Laboratories Determined to be Invalid
13	Laboratories Determined to be Outliers
189	Total Laboratorires Included in Analysis

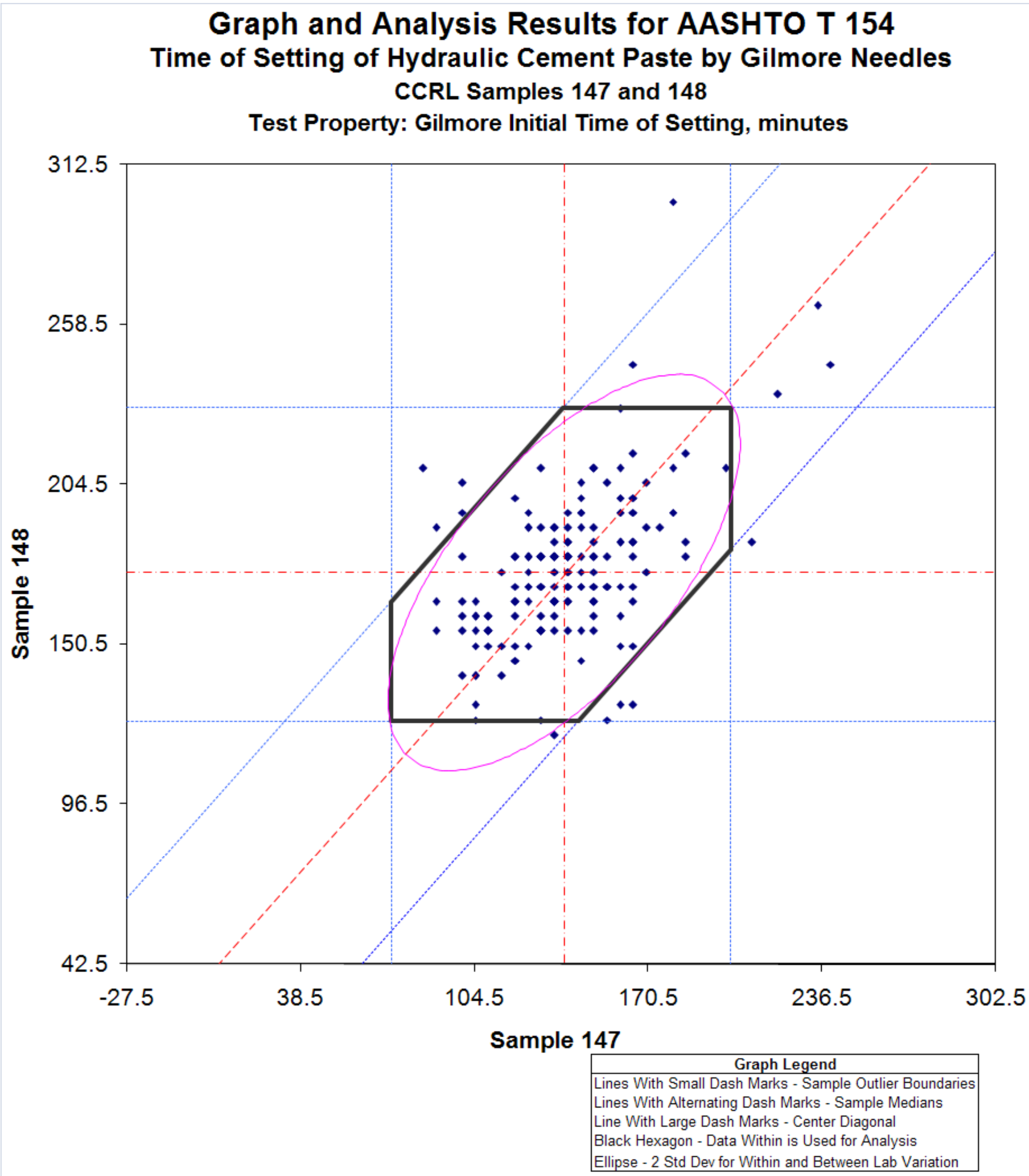
Average Results	
Sample 161 Average	Sample 162 Average
84	79

Repeatability			
1s	d2s	CV% (161)	CV% (162)
5.4	15.2	6.4	6.8

Reproducibility (Sample 161)		
1s	d2s	CV%
6.0	16.9	7.1

Reproducibility (Sample 162)		
1s	d2s	CV%
7.0	19.7	8.8

APPENDIX B: GILLMORE INITIAL TIME OF SETTING



Source of Data: AASHTO Materials Reference Laboratory Proficiency Sample Program
CCRL Samples 147 and 148
Final Report Issued March 2003

Participation:

174	Total Laboratories
1	Laboratories Determined to be Invalid
13	Laboratories Determined to be Outliers
160	Total Laboratorires Included in Analysis

Average Results	
Sample 147 Average	Sample 148 Average
139	175

Repeatability			
1s	d2s	CV% (147)	CV% (148)
13.2	37.3	9.5	7.6

Reproducability (Sample 147)		
1s	d2s	CV%
21.4	60.6	15.5

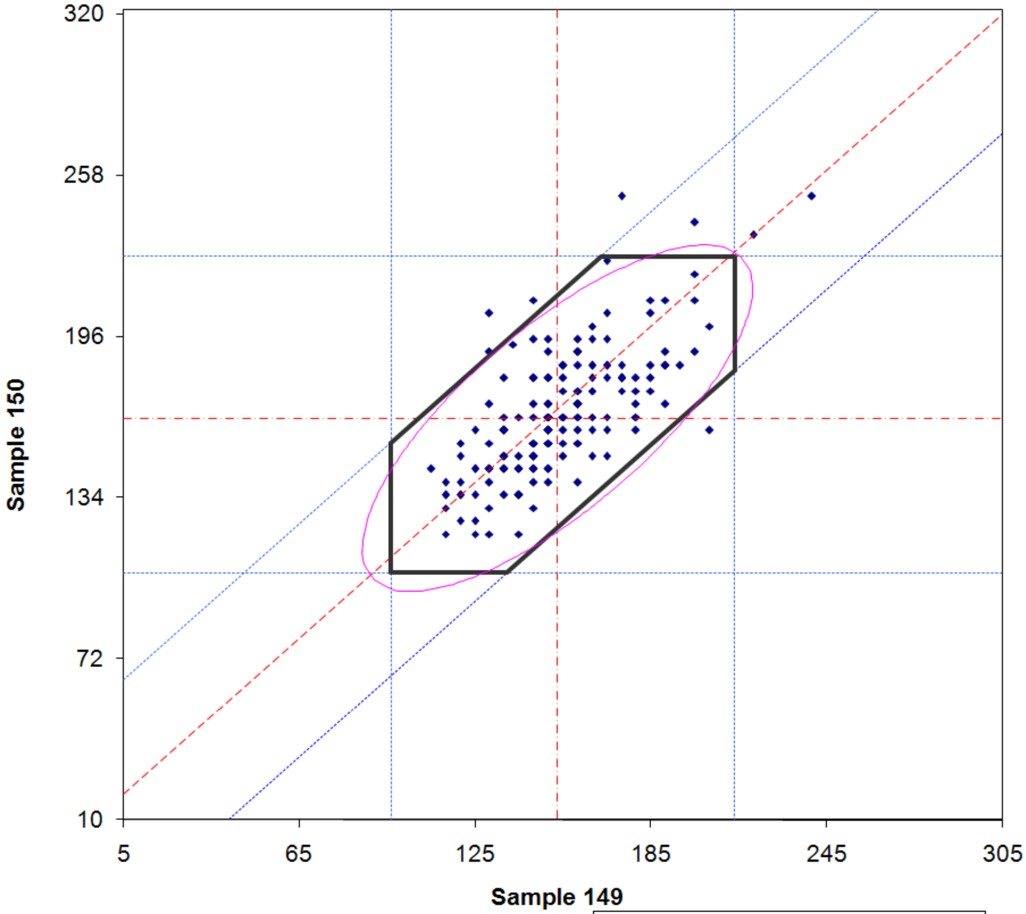
Reproducability (Sample 148)		
1s	d2s	CV%
19.0	53.7	10.9

Graph and Analysis Results for AASHTO T 154

Time of Setting of Hydraulic Cement Paste by Gilmore Needles

CCRL Samples 149 and 150

Test Property: Gilmore Initial Time of Setting, minutes



Graph Legend
Lines With Small Dash Marks - Sample Outlier Boundaries
Lines With Alternating Dash Marks - Sample Medians
Line With Large Dash Marks - Center Diagonal
Black Hexagon - Data Within is Used for Analysis
Ellipse - 2 Std Dev for Within and Between Lab Variation

Source of Data: AASHTO Materials Reference Laboratory Proficiency Sample Program
CCRL Samples 149 and 150
Final Report Issued September 2003

Participation:

172	Total Laboratories
0	Laboratories Determined to be Invalid
8	Laboratories Determined to be Outliers
164	Total Laboratorires Included in Analysis

Average Results	
Sample 149 Average	Sample 150 Average
153	165

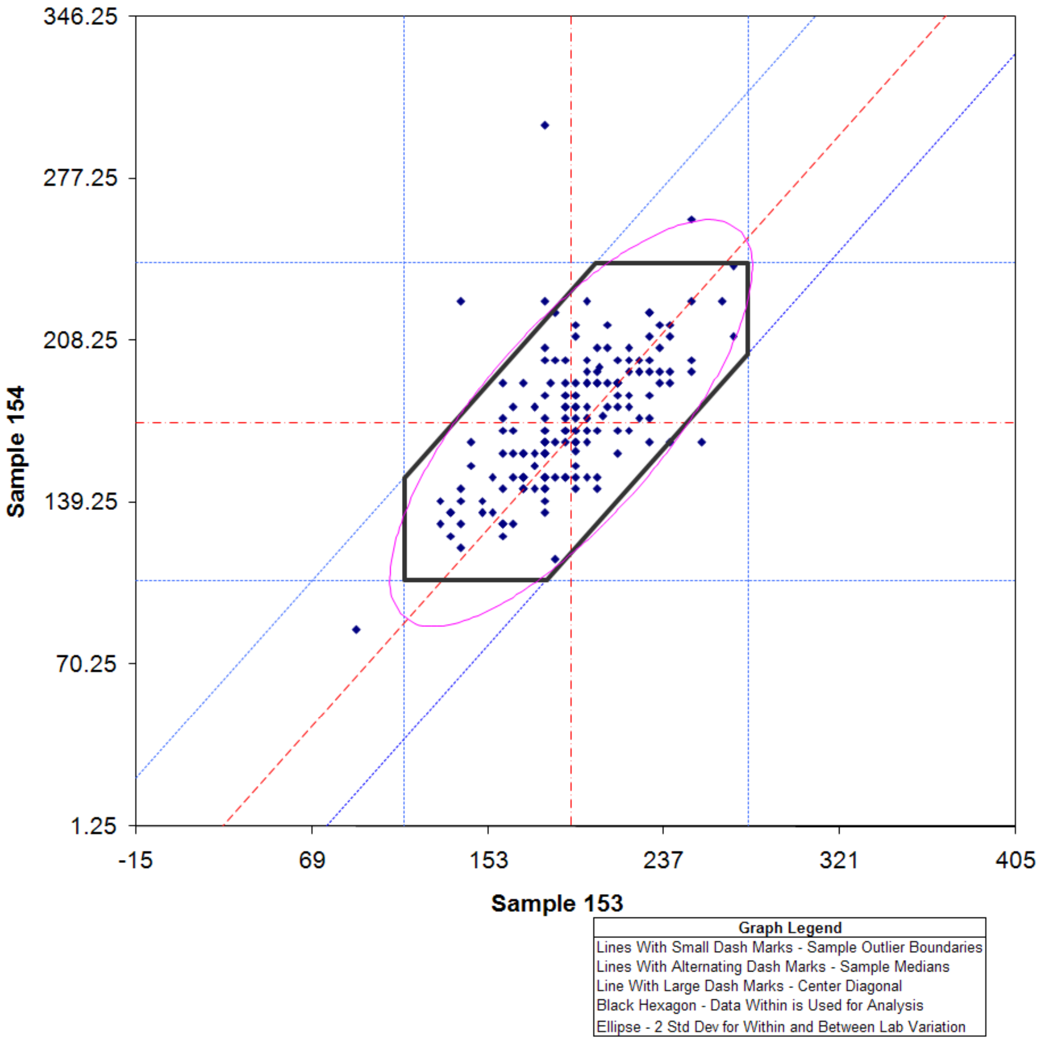
Repeatability			
1s	d2s	CV% (149)	CV% (150)
11.0	31.1	7.2	6.7

Reproducibility (Sample 149)		
1s	d2s	CV%
20.4	57.6	13.3

Reproducibility (Sample 150)		
1s	d2s	CV%
21.2	60.0	12.9

Graph and Analysis Results for AASHTO T 154
Time of Setting of Hydraulic Cement Paste by Gilmore Needles
CCRL Samples 153 and 154

Test Property: Gilmore Initial Time of Setting, minutes



Source of Data: AASHTO Materials Reference Laboratory Proficiency Sample Program
CCRL Samples 153 and 154
Final Report Issued October 2004

Participation:

175	Total Laboratories
2	Laboratories Determined to be Invalid
5	Laboratories Determined to be Outliers
168	Total Laboratorires Included in Analysis

Average Results	
Sample 153 Average	Sample 154 Average
193	173

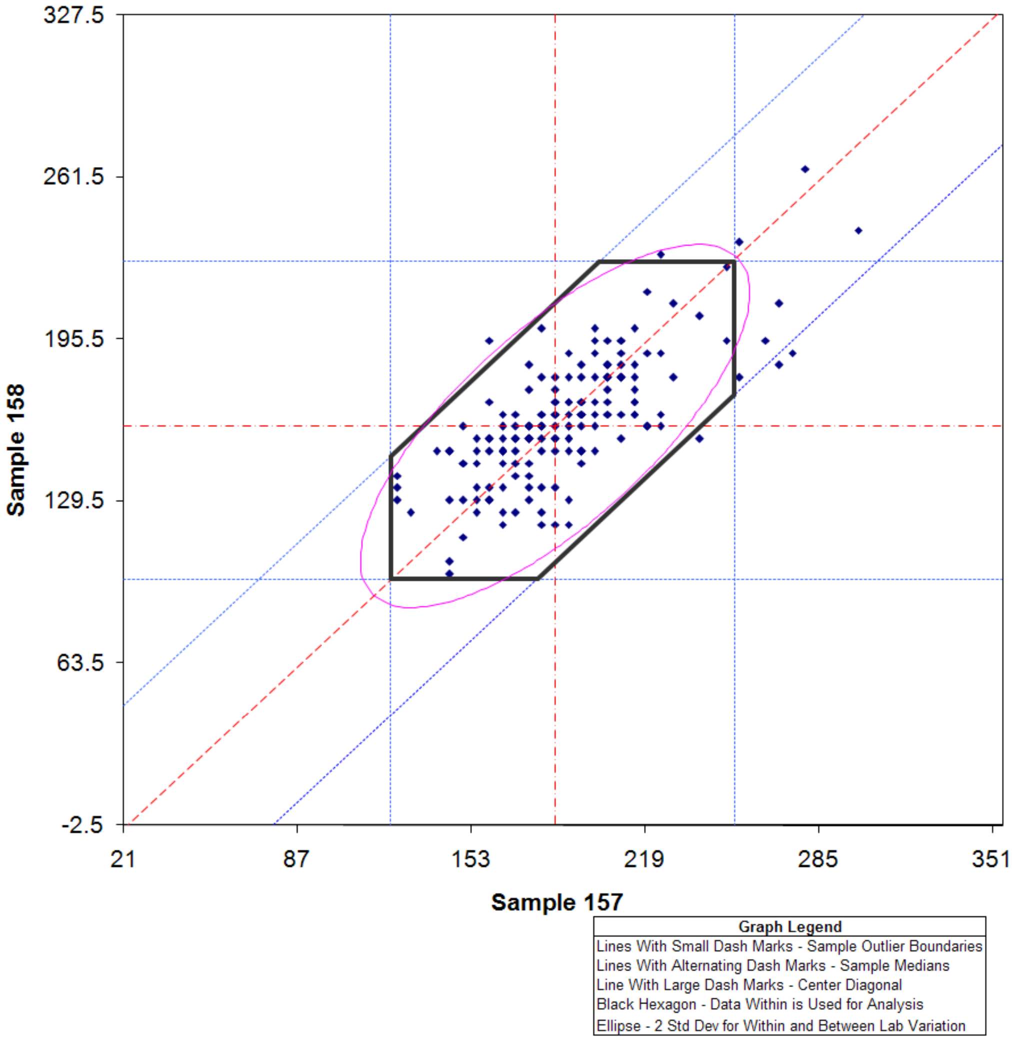
Repeatability			
1s	d2s	CV% (153)	CV% (154)
14.0	39.7	7.3	8.1

Reproducability (Sample 153)		
1s	d2s	CV%
28.6	80.9	14.8

Reproducability (Sample 154)		
1s	d2s	CV%
25.5	72.2	14.8

Graph and Analysis Results for AASHTO T 154
Time of Setting of Hydraulic Cement Paste by Gilmore Needles
CCRL Samples 157 and 158

Test Property: Gilmore Initial Time of Setting, minutes



Source of Data: AASHTO Materials Reference Laboratory Proficiency Sample Program
CCRL Samples 157 and 158
Final Report Issued October 2005

Participation:

176	Total Laboratories
0	Laboratories Determined to be Invalid
11	Laboratories Determined to be Outliers
165	Total Laboratorires Included in Analysis

Average Results	
Sample 157 Average	Sample 158 Average
185	160

Repeatability			
1s	d2s	CV% (157)	CV% (158)
12.6	35.7	6.8	7.9

Reproducibility (Sample 157)		
1s	d2s	CV%
24.2	68.5	13.1

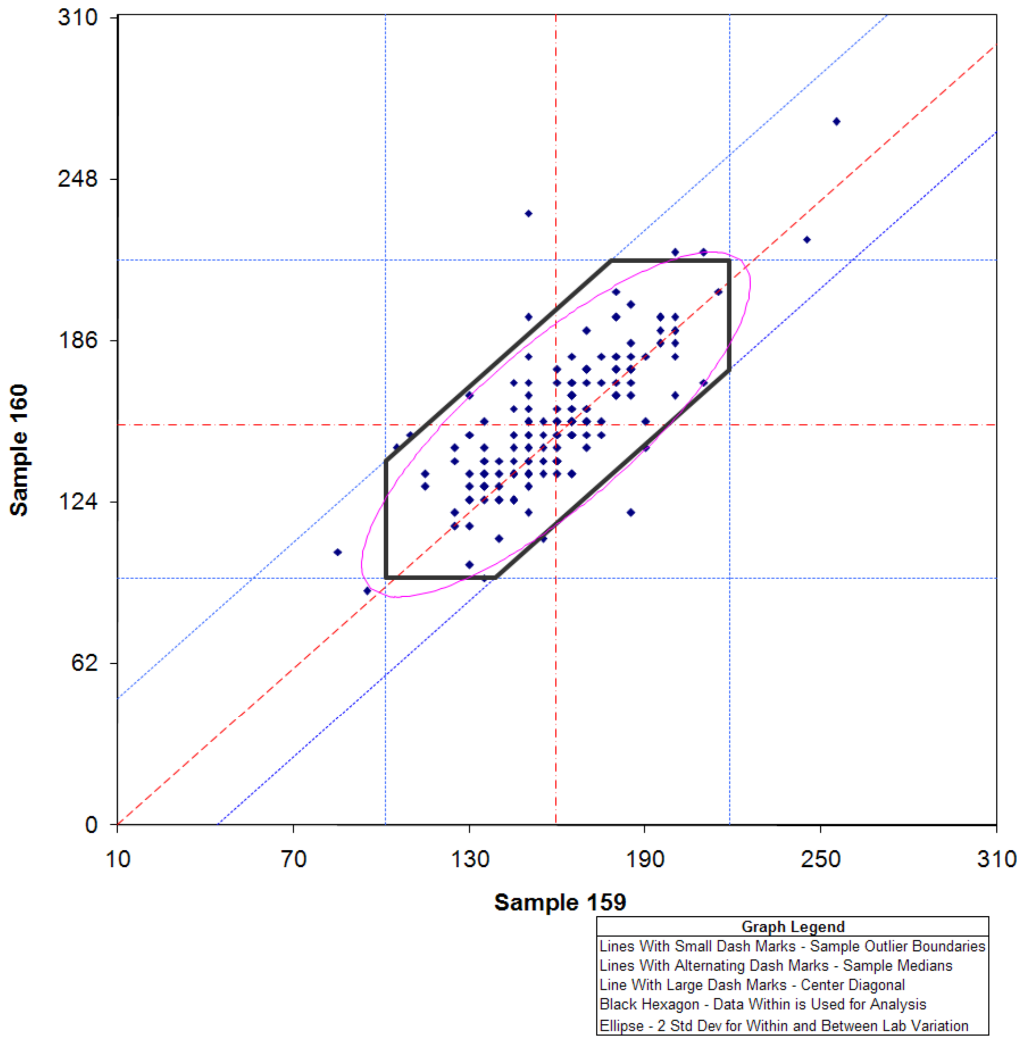
Reproducibility (Sample 158)		
1s	d2s	CV%
21.6	61.2	13.5

Graph and Analysis Results for AASHTO T 154

Time of Setting of Hydraulic Cement Paste by Gilmore Needles

CCRL Samples 159 and 160

Test Property: Gilmore Initial Time of Setting, minutes



Source of Data: AASHTO Materials Reference Laboratory Proficiency Sample Program
CCRL Samples 159 and 160
Final Report Issued April 2006

Participation:

175	Total Laboratories
1	Laboratories Determined to be Invalid
13	Laboratories Determined to be Outliers
161	Total Laboratorires Included in Analysis

Average Results	
Sample 159 Average	Sample 160 Average
159	154

Repeatability			
1s	d2s	CV% (159)	CV% (160)
9.6	27.1	6.0	6.2

Reproducibility (Sample 159)		
1s	d2s	CV%
20.6	58.1	12.9

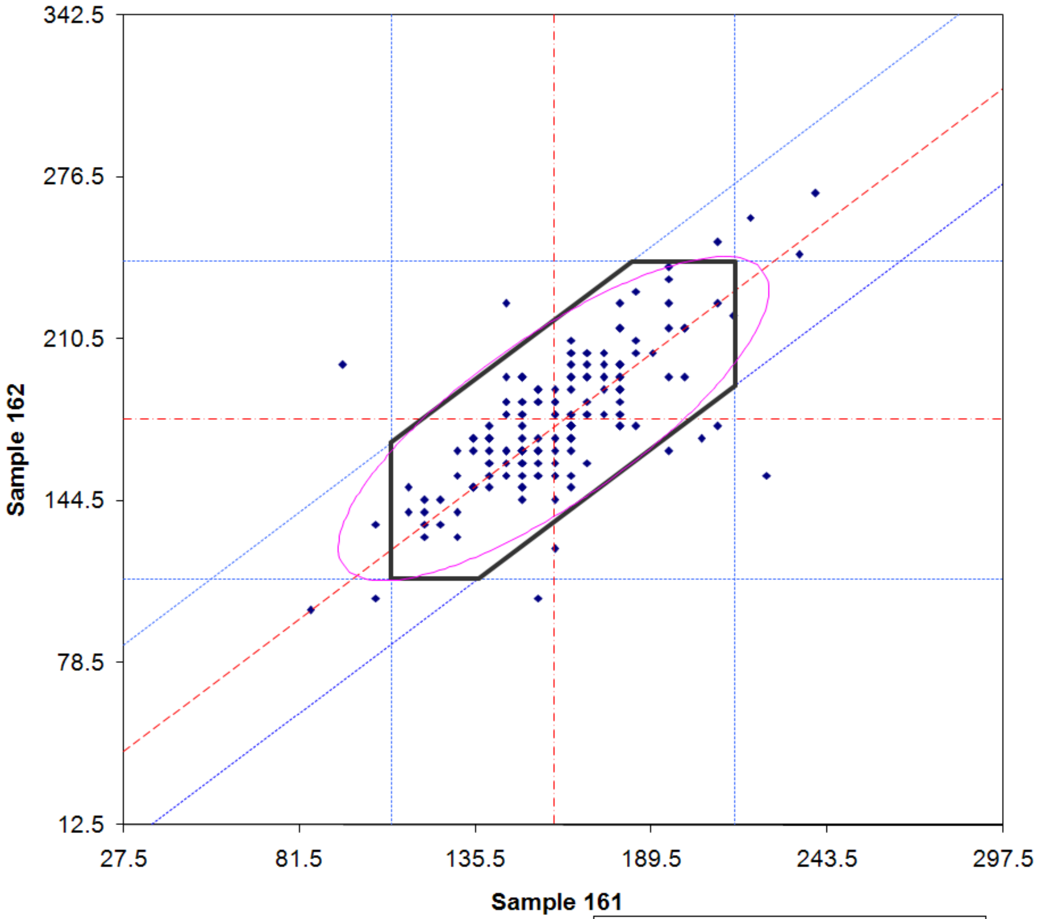
Reproducibility (Sample 160)		
1s	d2s	CV%
21.5	60.7	13.9

Graph and Analysis Results for AASHTO T 154

Time of Setting of Hydraulic Cement Paste by Gilmore Needles

CCRL Samples 161 and 162

Test Property: Gilmore Initial Time of Setting, minutes



Graph Legend
Lines With Small Dash Marks - Sample Outlier Boundaries
Lines With Alternating Dash Marks - Sample Medians
Line With Large Dash Marks - Center Diagonal
Black Hexagon - Data Within is Used for Analysis
Ellipse - 2 Std Dev for Within and Between Lab Variation

Source of Data: AASHTO Materials Reference Laboratory Proficiency Sample Program
CCRL Samples 161 and 162
Final Report Issued October 2006

Participation:

171	Total Laboratories
2	Laboratories Determined to be Invalid
13	Laboratories Determined to be Outliers
156	Total Laboratorires Included in Analysis

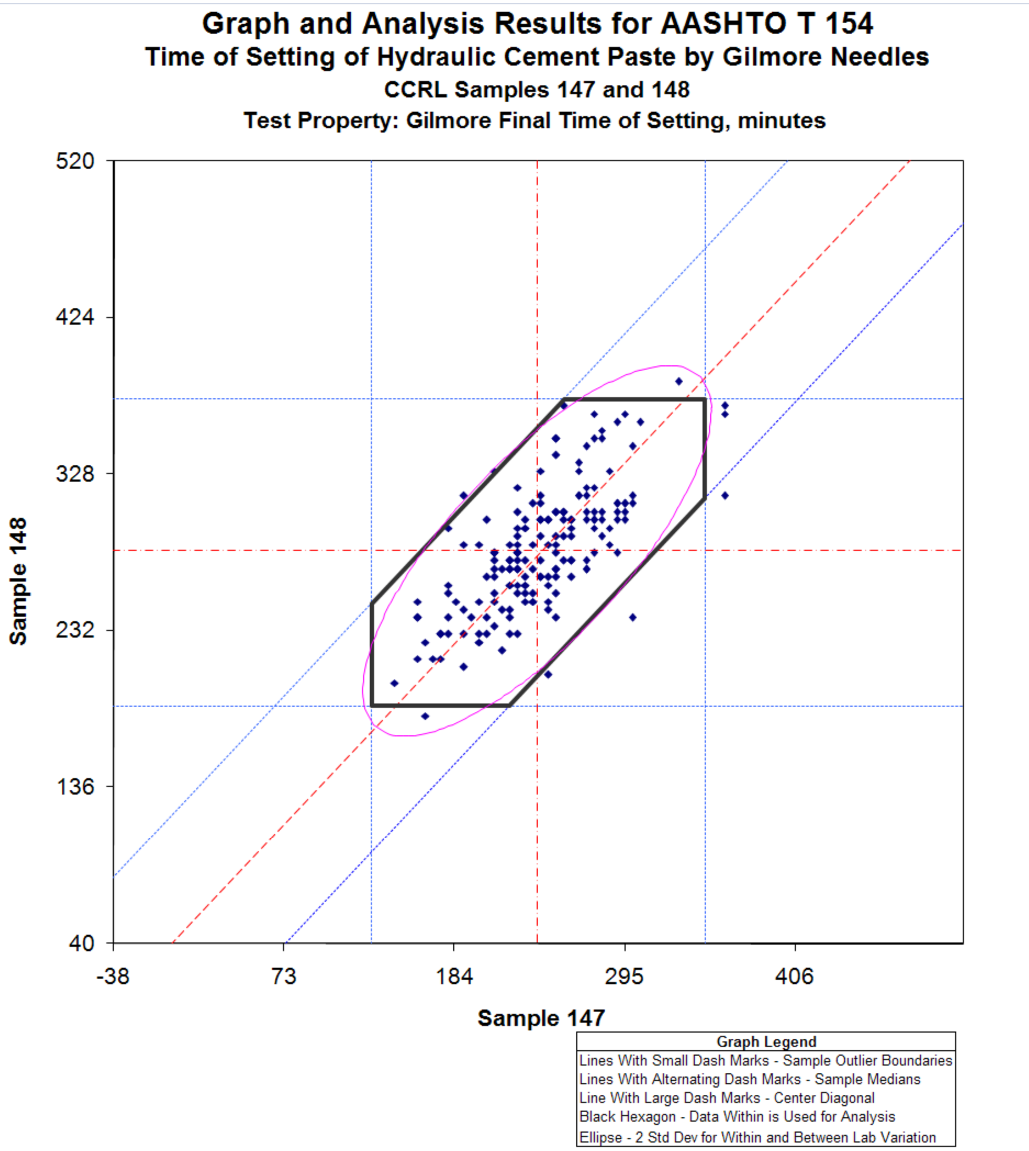
Average Results	
Sample 161 Average	Sample 162 Average
160	178

Repeatability			
1s	d2s	CV% (161)	CV% (162)
10.0	28.2	6.2	5.6

Reproducability (Sample 161)		
1s	d2s	CV%
19.4	54.8	12.1

Reproducability (Sample 162)		
1s	d2s	CV%
22.3	62.9	12.5

APPENDIX C: GILLMORE FINAL TIME OF SETTING



Source of Data: AASHTO Materials Reference Laboratory Proficiency Sample Program
CCRL Samples 147 and 148
Final Report Issued March 2003

Participation:

173	Total Laboratories
0	Laboratories Determined to be Invalid
9	Laboratories Determined to be Outliers
164	Total Laboratorires Included in Analysis

Average Results	
Sample 147 Average	Sample 148 Average
238	281

Repeatability			
1s	d2s	CV% (147)	CV% (148)
18.6	52.7	7.8	6.6

Reproducability (Sample 147)		
1s	d2s	CV%
35.4	100.2	14.9

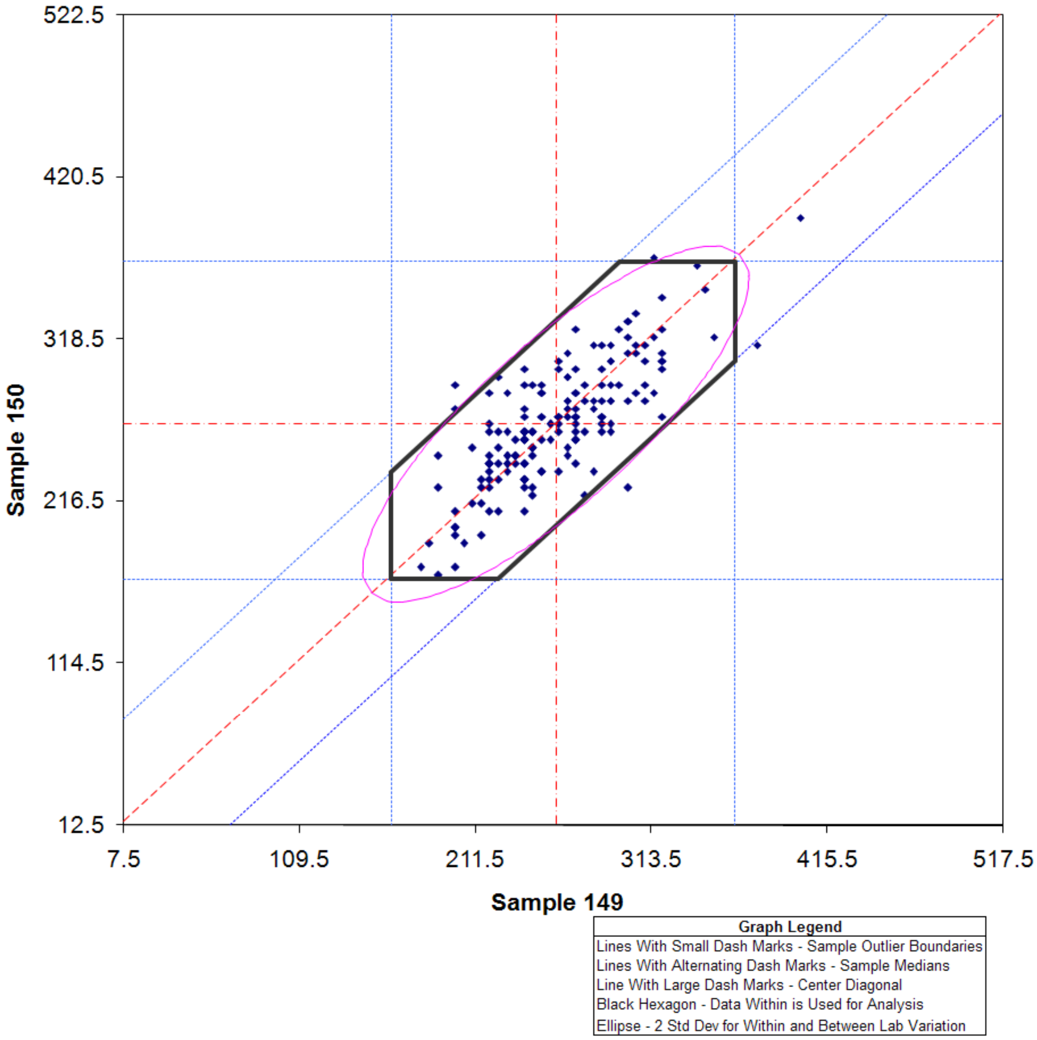
Reproducability (Sample 148)		
1s	d2s	CV%
35.6	100.7	12.7

Graph and Analysis Results for AASHTO T 154

Time of Setting of Hydraulic Cement Paste by Gilmore Needles

CCRL Samples 149 and 150

Test Property: Gilmore Final Time of Setting, minutes



Source of Data: AASHTO Materials Reference Laboratory Proficiency Sample Program
CCRL Samples 149 and 150
Final Report Issued September 2003

Participation:

172	Total Laboratories
0	Laboratories Determined to be Invalid
6	Laboratories Determined to be Outliers
166	Total Laboratorires Included in Analysis

Average Results	
Sample 149 Average	Sample 150 Average
258	265

Repeatability			
1s	d2s	CV% (149)	CV% (150)
16.0	45.2	6.2	6.0

Reproducability (Sample 149)		
1s	d2s	CV%
35.0	99.0	13.5

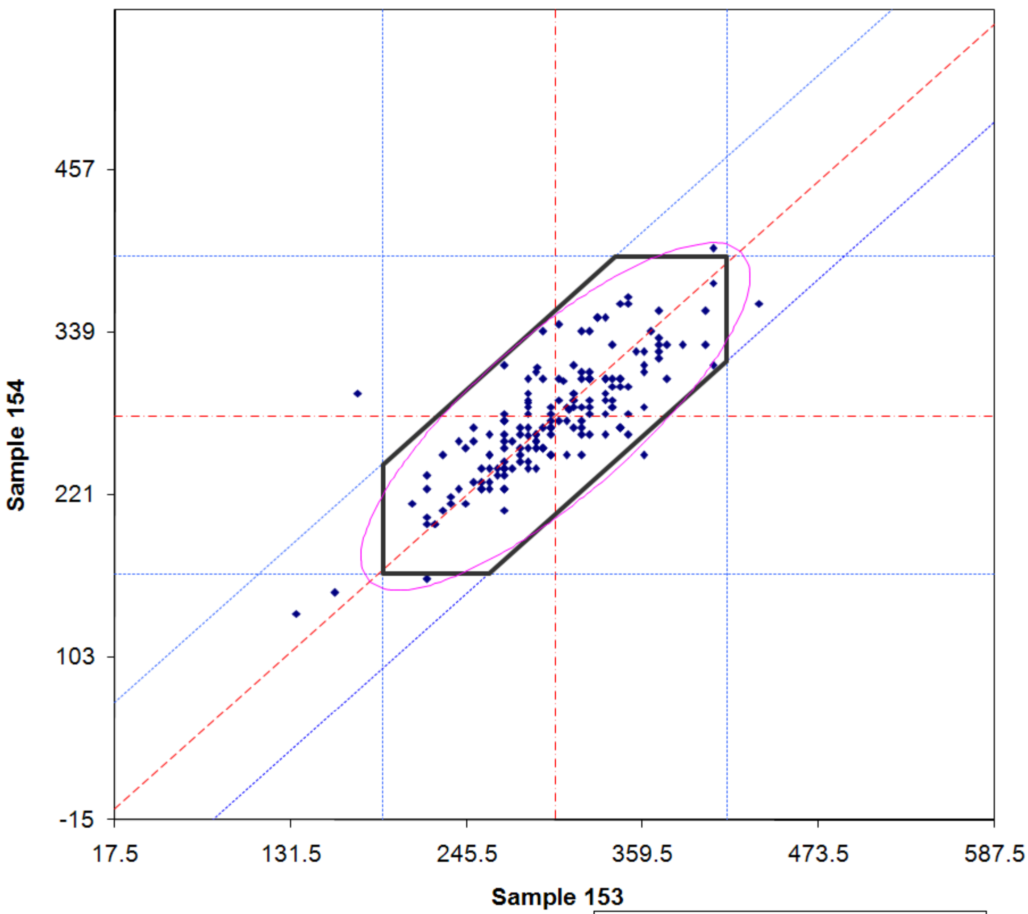
Reproducability (Sample 150)		
1s	d2s	CV%
36.1	102.2	13.6

Graph and Analysis Results for AASHTO T 154

Time of Setting of Hydraulic Cement Paste by Gilmore Needles

CCRL Samples 153 and 154

Test Property: Gilmore Final Time of Setting, minutes



Graph Legend
Lines With Small Dash Marks - Sample Outlier Boundaries
Lines With Alternating Dash Marks - Sample Medians
Line With Large Dash Marks - Center Diagonal
Black Hexagon - Data Within is Used for Analysis
Ellipse - 2 Std Dev for Within and Between Lab Variation

Source of Data: AASHTO Materials Reference Laboratory Proficiency Sample Program
CCRL Samples 153 and 154
Final Report Issued October 2004

Participation:

173	Total Laboratories
1	Laboratories Determined to be Invalid
6	Laboratories Determined to be Outliers
166	Total Laboratorires Included in Analysis

Average Results	
Sample 153 Average	Sample 154 Average
303	278

Repeatability			
1s	d2s	CV% (153)	CV% (154)
18.3	51.7	6.0	6.6

Reproducibility (Sample 153)		
1s	d2s	CV%
41.8	118.1	13.8

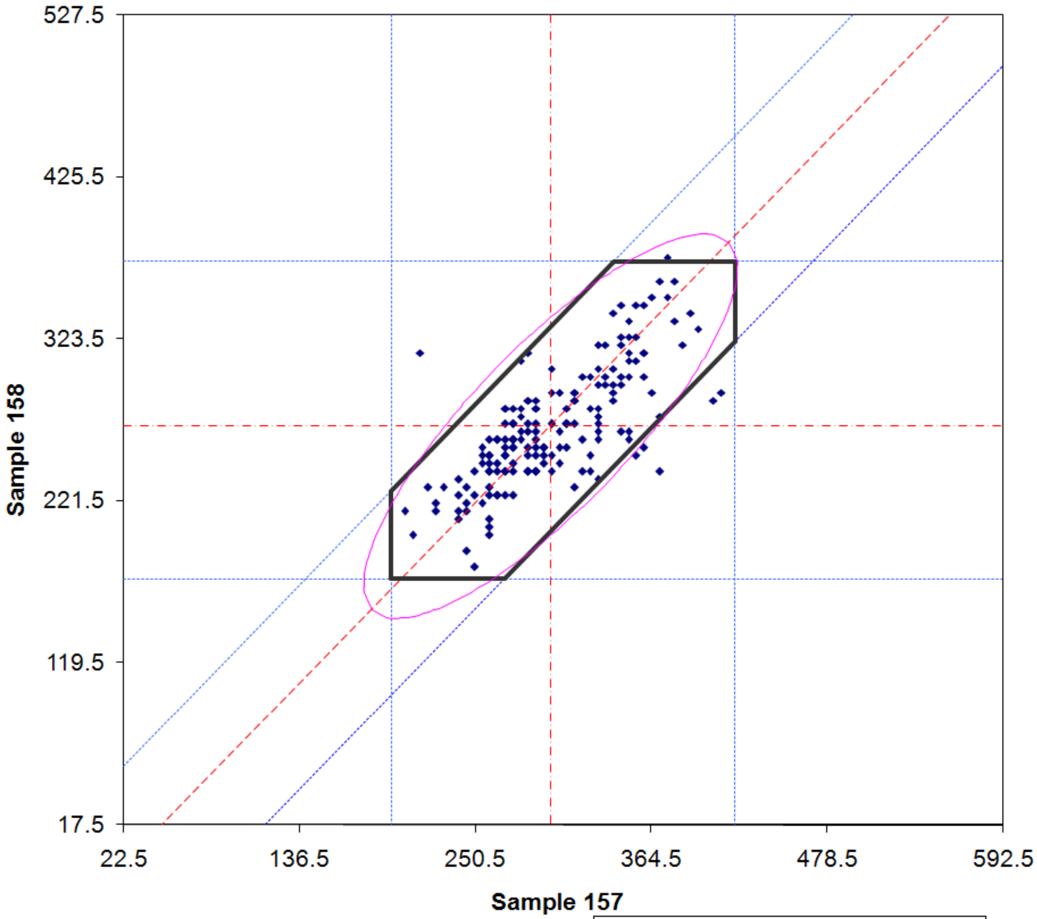
Reproducibility (Sample 154)		
1s	d2s	CV%
38.1	107.9	13.7

Graph and Analysis Results for AASHTO T 154

Time of Setting of Hydraulic Cement Paste by Gilmore Needles

CCRL Samples 157 and 158

Test Property: Gilmore Final Time of Setting, minutes



Graph Legend
Lines With Small Dash Marks - Sample Outlier Boundaries
Lines With Alternating Dash Marks - Sample Medians
Line With Large Dash Marks - Center Diagonal
Black Hexagon - Data Within is Used for Analysis
Ellipse - 2 Std Dev for Within and Between Lab Variation

Source of Data: AASHTO Materials Reference Laboratory Proficiency Sample Program
CCRL Samples 157 and 158
Final Report Issued October 2005

Participation:

175	Total Laboratories
1	Laboratories Determined to be Invalid
6	Laboratories Determined to be Outliers
168	Total Laboratorires Included in Analysis

Average Results	
Sample 157 Average	Sample 158 Average
299	269

Repeatability			
1s	d2s	CV% (157)	CV% (158)
16.9	47.9	5.7	6.3

Reproducibility (Sample 157)		
1s	d2s	CV%
40.2	113.8	13.4

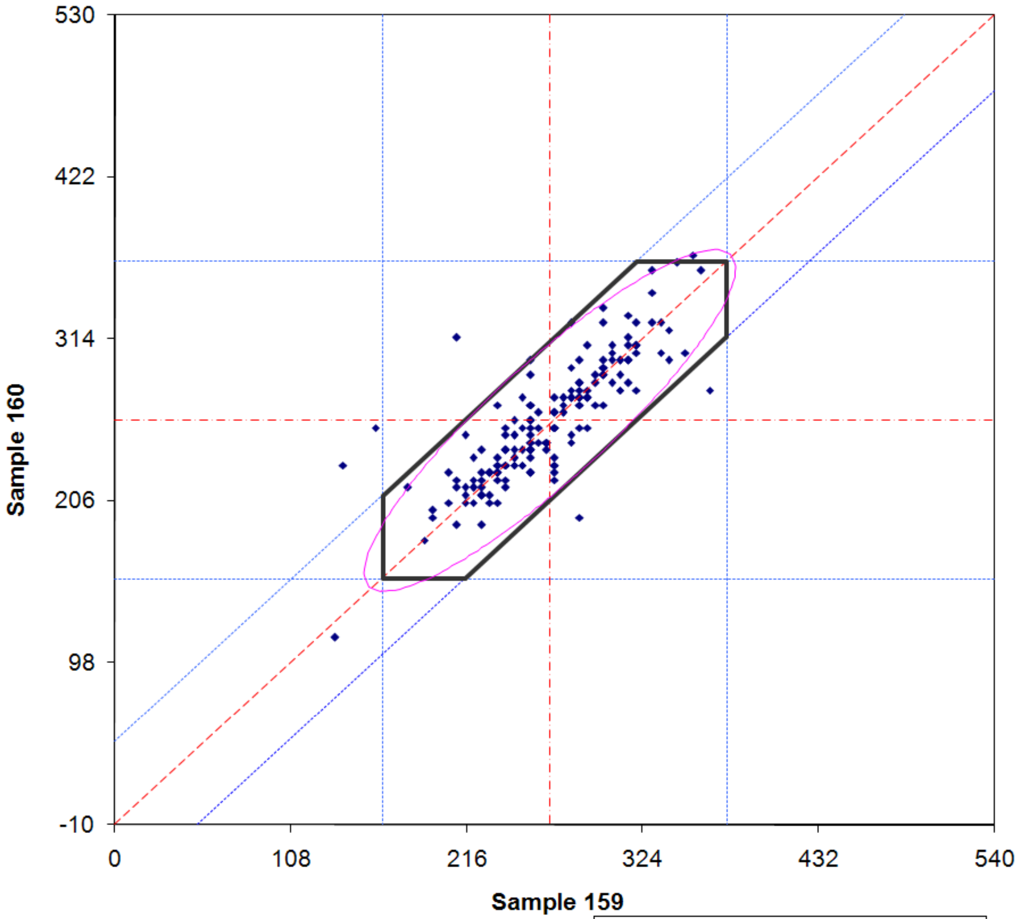
Reproducibility (Sample 158)		
1s	d2s	CV%
36.7	103.8	13.7

Graph and Analysis Results for AASHTO T 154

Time of Setting of Hydraulic Cement Paste by Gilmore Needles

CCRL Samples 159 and 160

Test Property: Gilmore Final Time of Setting, minutes



Graph Legend
Lines With Small Dash Marks - Sample Outlier Boundaries
Lines With Alternating Dash Marks - Sample Medians
Line With Large Dash Marks - Center Diagonal
Black Hexagon - Data Within is Used for Analysis
Ellipse - 2 Std Dev for Within and Between Lab Variation

Source of Data: AASHTO Materials Reference Laboratory Proficiency Sample Program
CCRL Samples 159 and 160
Final Report Issued April 2006

Participation:

174	Total Laboratories
3	Laboratories Determined to be Invalid
4	Laboratories Determined to be Outliers
167	Total Laboratorires Included in Analysis

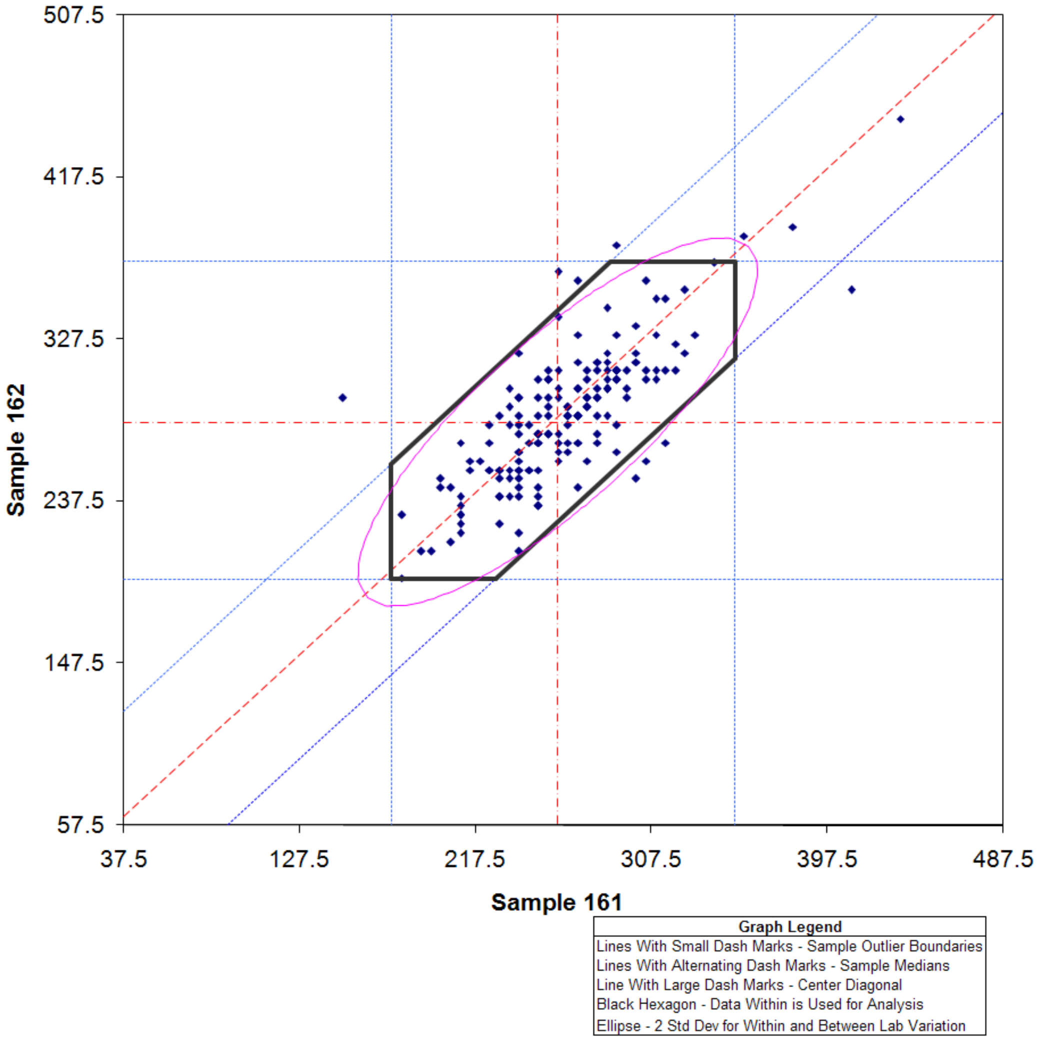
Average Results	
Sample 159 Average	Sample 160 Average
267	260

Repeatability			
1s	d2s	CV% (159)	CV% (160)
12.4	35.1	4.6	4.8

Reproducibility (Sample 159)		
1s	d2s	CV%
36.4	102.9	13.6

Reproducibility (Sample 160)		
1s	d2s	CV%
37.5	106.2	14.4

Graph and Analysis Results for AASHTO T 154
Time of Setting of Hydraulic Cement Paste by Gilmore Needles
CCRL Samples 161 and 162
Test Property: Gilmore Final Time of Setting, minutes



Source of Data: AASHTO Materials Reference Laboratory Proficiency Sample Program
CCRL Samples 161 and 162
Final Report Issued October 2006

Participation:

171	Total Laboratories
2	Laboratories Determined to be Invalid
9	Laboratories Determined to be Outliers
160	Total Laboratorires Included in Analysis

Average Results	
Sample 161 Average	Sample 162 Average
260	282

Repeatability			
1s	d2s	CV% (161)	CV% (162)
14.4	40.8	5.5	5.1

Reproducibility (Sample 161)		
1s	d2s	CV%
31.8	90.1	12.3

Reproducibility (Sample 162)		
1s	d2s	CV%
33.1	93.7	11.8

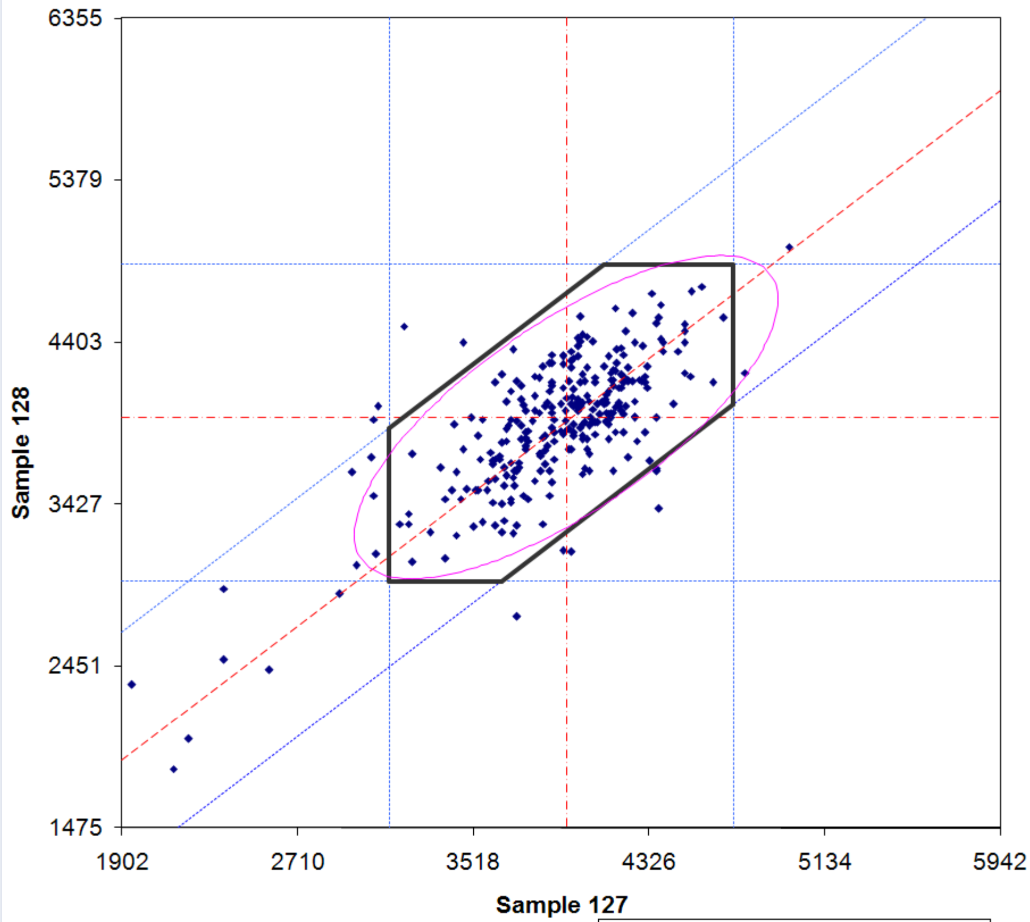
APPENDIX D: COMPRESSIVE STRENGTH

Graph and Analysis Results for AASHTO T 22

Compressive Strength of Cylindrical Concrete Specimens

CCRL Samples 127 and 128

Test Property: 7-Day Compressive Strength of 4x8 Specimens, psi



Graph Legend
Lines With Small Dash Marks - Sample Outlier Boundaries
Lines With Alternating Dash Marks - Sample Medians
Line With Large Dash Marks - Center Diagonal
Black Hexagon - Data Within is Used for Analysis
Ellipse - 2 Std Dev for Within and Between Lab Variation

Source of Data: AASHTO Materials Reference Laboratory Proficiency Sample Program
CCRL Samples 127 and 128
Final Report Issued June 2003

Participation:

293	Total Laboratories
7	Laboratories Determined to be Invalid
19	Laboratories Determined to be Outliers
267	Total Laboratorires Included in Analysis

Average Results	
Sample 127 Average	Sample 128 Average
3945	3952

Repeatability			
1s	d2s	CV% (127)	CV% (128)
168.5	476.7	4.3	4.3

Reproducability (Sample 127)		
1s	d2s	CV%
281.7	796.8	7.1

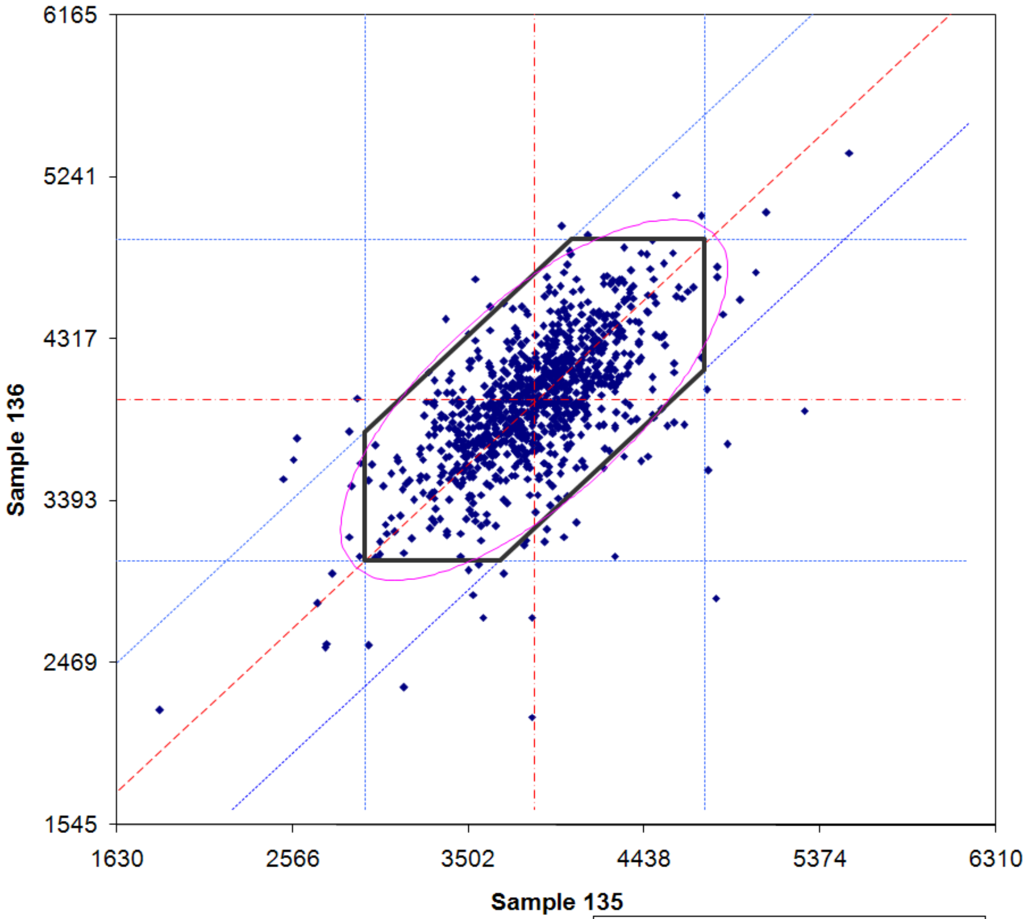
Reproducability (Sample 128)		
1s	d2s	CV%
321.5	909.5	8.1

Graph and Analysis Results for AASHTO T 22

Compressive Strength of Cylindrical Concrete Specimens

CCRL Samples 135 and 136

Test Property: 7-Day Compressive Strength of 6x12 Specimens, psi



Graph Legend

Lines With Small Dash Marks - Sample Outlier Boundaries
Lines With Alternating Dash Marks - Sample Medians
Line With Large Dash Marks - Center Diagonal
Black Hexagon - Data Within is Used for Analysis
Ellipse - 2 Std Dev for Within and Between Lab Variation

Source of Data: AASHTO Materials Reference Laboratory Proficiency Sample Program
CCRL Samples 135 and 136
Final Report Issued July 2005

Participation:

970	Total Laboratories
9	Laboratories Determined to be Invalid
51	Laboratories Determined to be Outliers
910	Total Laboratorires Included in Analysis

Average Results	
Sample 135 Average	Sample 136 Average
3851	3970

Repeatability			
1s	d2s	CV% (135)	CV% (136)
181.9	514.4	4.7	4.6

Reproducibility (Sample 135)		
1s	d2s	CV%
314.4	889.1	8.2

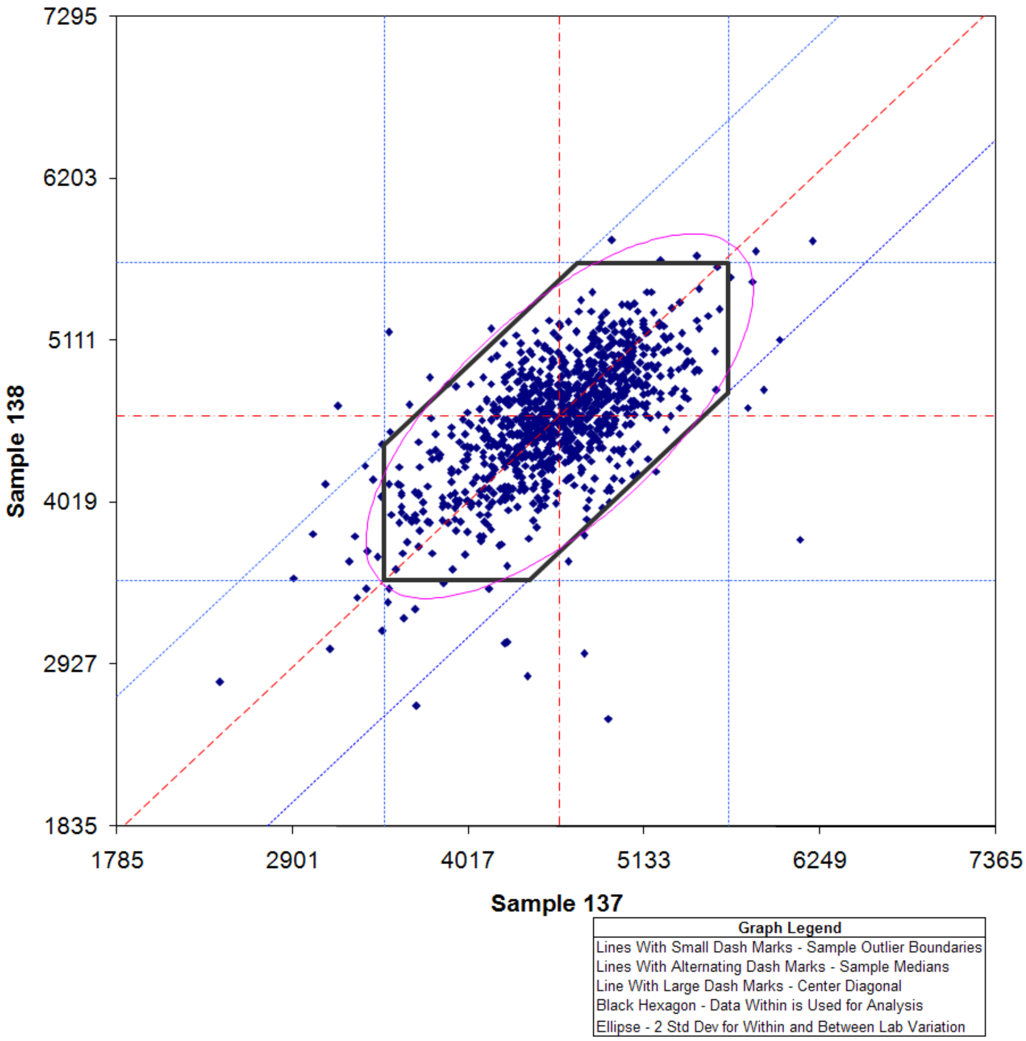
Reproducibility (Sample 136)		
1s	d2s	CV%
321.7	909.9	8.1

Graph and Analysis Results for AASHTO T 22

Compressive Strength of Cylindrical Concrete Specimens

CCRL Samples 137 and 138

Test Property: 7-Day Compressive Strength of 6x12 Specimens, psi



Source of Data: AASHTO Materials Reference Laboratory Proficiency Sample Program
CCRL Samples 137 and 138
Final Report Issued February 2006

Participation:

985	Total Laboratories
7	Laboratories Determined to be Invalid
43	Laboratories Determined to be Outliers
935	Total Laboratorires Included in Analysis

Average Results	
Sample 137 Average	Sample 138 Average
4596	4601

Repeatability			
1s	d2s	CV% (137)	CV% (138)
228.5	646.4	5.0	5.0

Reproducability (Sample 137)		
1s	d2s	CV%
394.5	1115.9	8.6

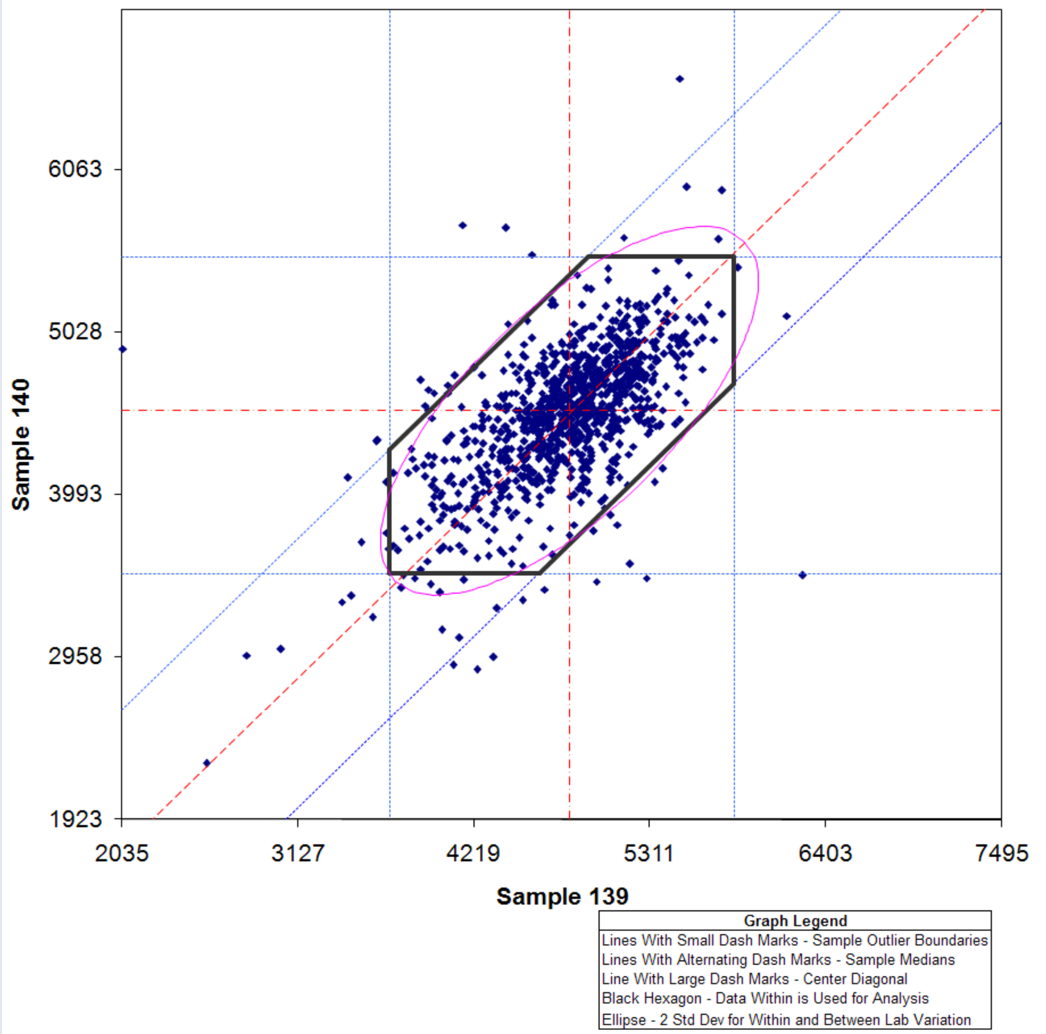
Reproducability (Sample 138)		
1s	d2s	CV%
357.4	1010.9	7.8

Graph and Analysis Results for AASHTO T 22

Compressive Strength of Cylindrical Concrete Specimens

CCRL Samples 139 and 140

Test Property: 7-Day Compressive Strength of 6x12 Specimens, psi



Source of Data: AASHTO Materials Reference Laboratory Proficiency Sample Program
CCRL Samples 139 and 140
Final Report Issued June 2006

Participation:

1034	Total Laboratories
8	Laboratories Determined to be Invalid
47	Laboratories Determined to be Outliers
979	Total Laboratorires Included in Analysis

Average Results	
Sample 139 Average	Sample 140 Average
4812	4526

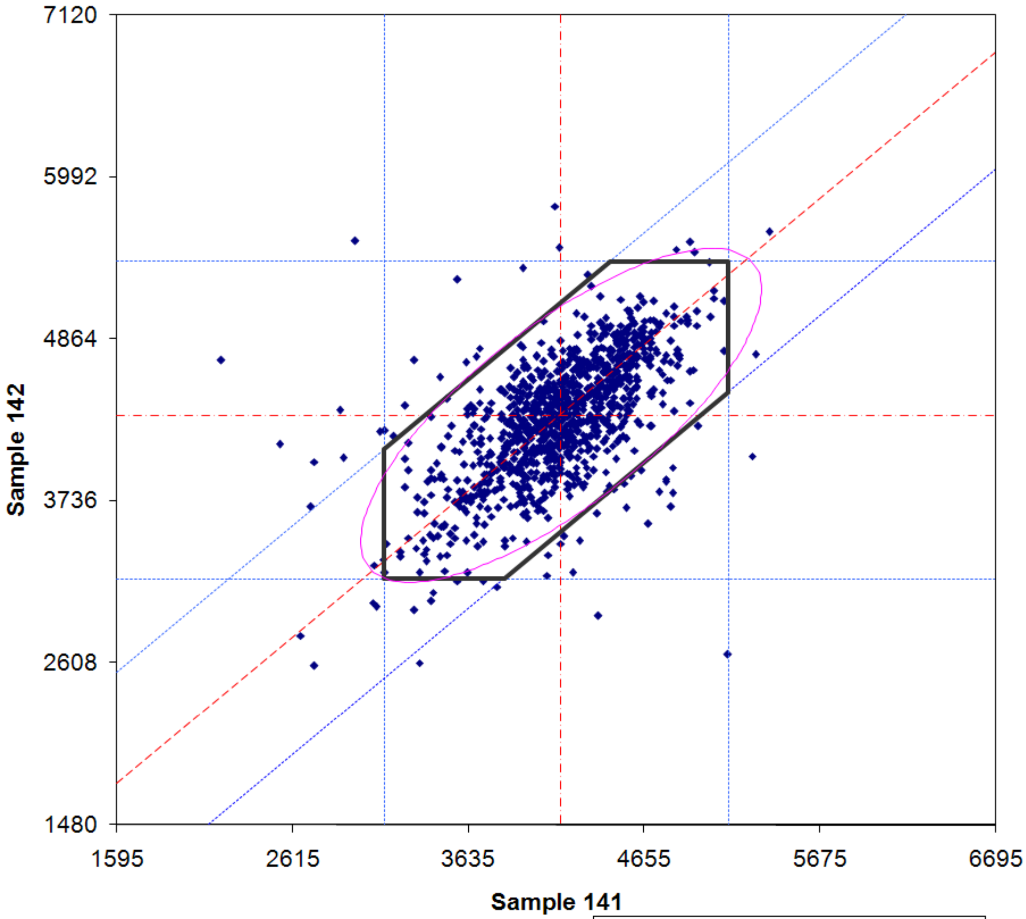
Repeatability			
1s	d2s	CV% (139)	CV% (140)
212.5	601.1	4.4	4.7

Reproducability (Sample 139)		
1s	d2s	CV%
369.0	1043.6	7.7

Reproducability (Sample 140)		
1s	d2s	CV%
352.5	997.0	7.8

Graph and Analysis Results for AASHTO T 22
Compressive Strength of Cylindrical Concrete Specimens
CCRL Samples 141 and 142

Test Property: 7-Day Compressive Strength of 6x12 Specimens, psi



Graph Legend
Lines With Small Dash Marks - Sample Outlier Boundaries
Lines With Alternating Dash Marks - Sample Medians
Line With Large Dash Marks - Center Diagonal
Black Hexagon - Data Within is Used for Analysis
Ellipse - 2 Std Dev for Within and Between Lab Variation

Source of Data: AASHTO Materials Reference Laboratory Proficiency Sample Program
CCRL Samples 141 and 142
Final Report Issued January 2007

Participation:

1065	Total Laboratories
8	Laboratories Determined to be Invalid
55	Laboratories Determined to be Outliers
1002	Total Laboratorires Included in Analysis

Average Results	
Sample 141 Average	Sample 142 Average
4173	4334

Repeatability			
1s	d2s	CV% (141)	CV% (142)
191.5	541.8	4.6	4.4

Reproducability (Sample 141)		
1s	d2s	CV%
342.8	969.6	8.2

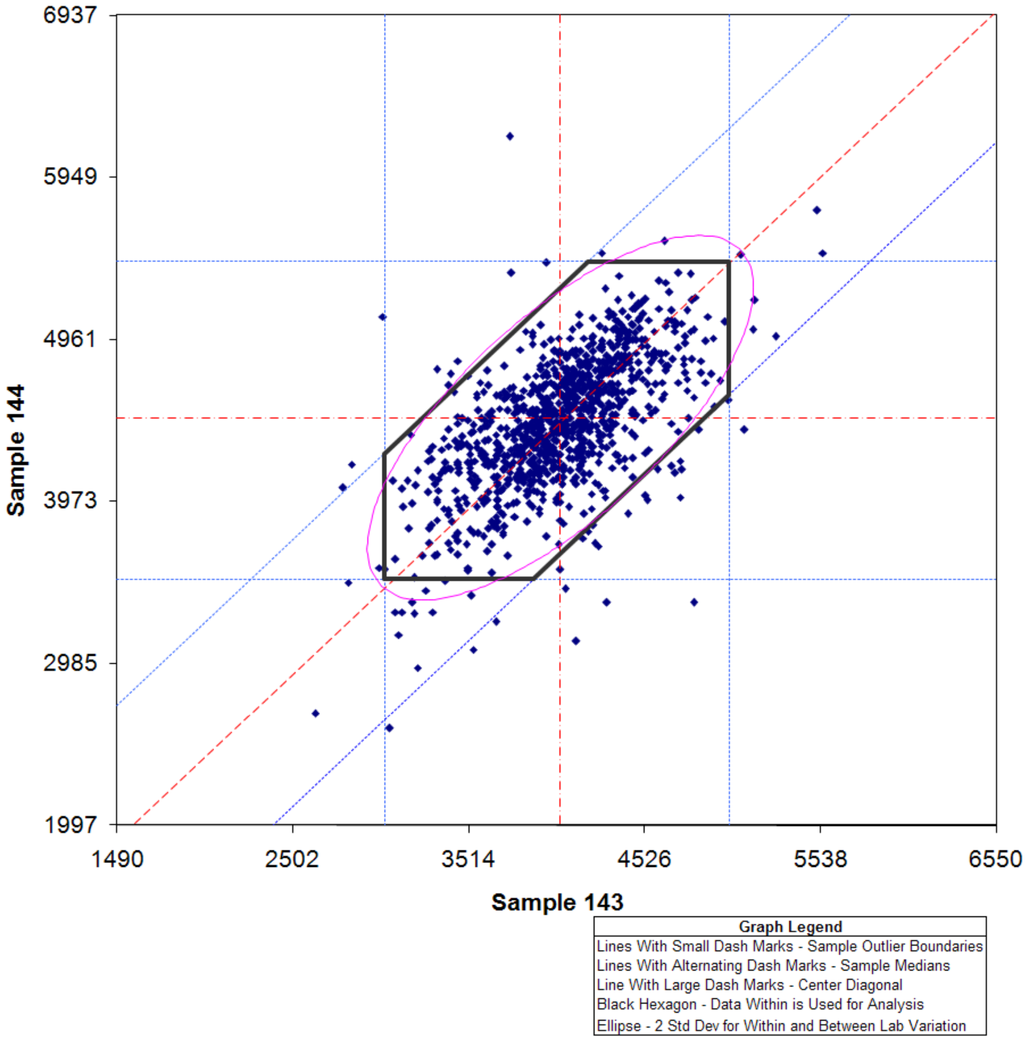
Reproducability (Sample 142)		
1s	d2s	CV%
382.5	1082.0	8.8

Graph and Analysis Results for AASHTO T 22

Compressive Strength of Cylindrical Concrete Specimens

CCRL Samples 143 and 144

Test Property: 7-Day Compressive Strength of 6x12 Specimens, psi



Source of Data: AASHTO Materials Reference Laboratory Proficiency Sample Program
CCRL Samples 143 and 144
Final Report Issued June 2007

Participation:

1058	Total Laboratories
12	Laboratories Determined to be Invalid
52	Laboratories Determined to be Outliers
994	Total Laboratorires Included in Analysis

Average Results	
Sample 143 Average	Sample 144 Average
4042	4484

Repeatability			
1s	d2s	CV% (143)	CV% (144)
197.4	558.3	4.9	4.4

Reproducability (Sample 143)		
1s	d2s	CV%
346.2	979.1	8.6

Reproducability (Sample 144)		
1s	d2s	CV%
340.2	962.4	7.6