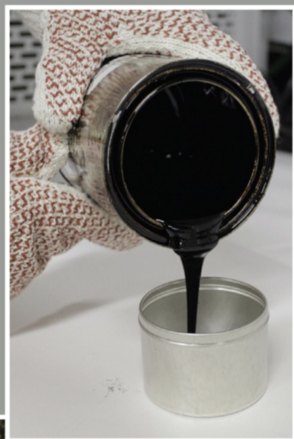
NCAT Report 14-01



Results of Inter-laboratory Study for AMPT Pooled Fund Study TPF-5(178)

By
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April 2014

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1. Report No. NCAT Report No. 14-01	2. Government Accession No	3. Recipient's Catalog No
4. Title and Subtitle Results of Inter-Laboratory Study for AMPT Pooled Fund Study TPF-5(178)		5. Report Date April 2014
		6. Performing Organization Code
7. Authors Adam J. Taylor, P.E. and Nam H. Tran, Ph.D., P.E., LEED GA		8. Performing Organization Report No. NCAT Report No. 14-01
9. Performing Organization Name and Address National Center for Asphalt Technology at Auburn University 277 Technology Parkway, Auburn, AL 36830		10. Work Unit No.
		11. Contract or Grant No.
12. Sponsoring Agency Name and Address Federal Highway Administration Office of Pavement Technology 1200 New Jersey Avenue, SE Washington DC 20590		13. Type of Report and Period Covered Final
		14. Sponsoring Agency Code
15. Supplementary Notes		

16. Abstract

An inter-laboratory study (ILS) was conducted as part of Pooled Fund Study TPF-5(178) to (1) help participating state agencies be familiarized with the AMPT and start using the AMPT to test their routine asphalt mixtures; (2) determine if the variability of the dynamic modulus and flow number test results obtained in this pooled-fund ILS was comparable with that determined under the NCHRP Project 09-29 ILS; and (3) investigate whether the current sample air void fabrication tolerances could be loosened from ± 0.5% to ± 1.0% as recommended in NCHRP Project 09-29. Twenty-nine participating laboratories were divided into three groups which were asked to test their specimens prepared from loose plant-produced mix at 6 ± 0.5%, 7 ± 0.5%, and 8 ± 0.5% air voids.

Twenty-two of the 29 laboratories returned dynamic modulus and flow number test results for analysis included in this report. The repeatability statistics of the pooled-fund ILS for dynamic modulus and phase angle were generally equivalent to or higher than the values obtained during the NCHRP Project 09-29 ILS, but the reproducibility statistics for the pooled-fund ILS was either equivalent to or lower than the values obtained in the previous ILS. For flow number, the repeatability and reproducibility statistics for each of the three groups were significantly improved over the NCHRP Project 09-29 ILS values. This may be because each of the participating labs followed a more consistent procedure for preparing test specimens in the pooled fund ILS and had received some uniform training from both the manufacturer and through the NHI AMPT training course.

The analysis results suggest that specimen air voids have a significant effect on both the dynamic modulus and flow number results. Up to approximately 50% of the variability of dynamic modulus results and approximately 70% of the variability of flow number data in this study can be explained by the variability of specimen air voids. In addition, a linear regression of the flow number data between 5.5 and 8.5 percent air voids showed a 1.0 percent increase in air void content would yield a flow number reduction of approximately 95 cycles. Thus, it is not possible to support loosening the specimen fabrication air void tolerances from ±0.5 percent to ±1.0 percent based on the results of this study.

17. Key Words AMPT, Dynamic Modulus, Flow Number, Inter-laboratory Study, Repeatability, Reproducibility	18. Distribution Statement No restriction. This document is available to the public through the National Technical Information Service 5285 Port Royal Road Springfield VA 22161		
19. Security Classif.(of this report) Unclassified	20. Security Classif. (of this page) Unclassified	21. No. of Pages 41	22. Price

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RESULTS OF INTER-LABORATORY STUDY FOR AMPT POOLED FUND STUDY TPF-5(178)

Final Report

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November 2013

ACKNOWLEDGEMENTS

This project was made possible by the Federal Highway Administration and the partner agencies of Transportation Pooled Fund Study TPF-5(178) Implementation of the Asphalt Mixture Performance Tester (AMPT) for Superpave Validation. The authors would like to thank the many personnel who contributed to the coordination and accomplishment of the work presented herein. Special thanks are extended to Jeffrey N. Withee, P.E., for serving as the technical representative.

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PROBLEM STATEMENT

An inter-laboratory study (ILS) was conducted under National Cooperative Highway Research Program (NCHRP) Project 09-29 (Bonaquist, 2011) to establish the precision statements for dynamic modulus and flow number tests conducted with the Asphalt Mixture Performance Tester (AMPT). That study utilized eight laboratories and two types of test specimens. The first type was compacted from laboratory-prepared loose mix samples sent to each participating laboratory, and the other was pre-fabricated in one laboratory in order to separate specimen fabrication and AMPT testing variability sources. Some key findings from the ILS include:

- The variability of dynamic modulus and confined flow number tests is acceptable, but the variability of unconfined flow number tests is unacceptable for the rutting resistance criteria developed in NCHRP Project 09-33.
- The air void tolerances should be changed to ±1.0 percent to be consistent with the tolerances used in the ILS for developing the precision statements.
- Specimen fabrication factors, including the compactor type, air void content, and specimen age, have significant but not systematic effects on the between-lab variability.
- Some improvements, including use of lower spring force sensors and improved guidance for fabrication and use of friction reducers, can reduce the test variability.

With the AMPT pooled-fund study (TPF-5(178)) supplying the AMPT equipment to participating highway agencies, it was desirable to conduct an inter-laboratory study with a larger number of users.

OBJECTIVE

The objective of this pooled-fund ILS was threefold:

- To help participating state agencies be familiar with the AMPT and to encourage the agencies to start using the AMPT to test their routine asphalt mixtures.
- To determine if the variability of the dynamic modulus and flow number test results obtained in this pooled-fund ILS was comparable with that determined under the NCHRP Project 09-29 ILS.
- To investigate whether the current sample air void fabrication tolerances could be loosened from ± 0.5 percent to ± 1.0 percent as recommended in NCHRP Project 09-29.

TESTING PLAN

Table 1 shows an experimental plan for this study. For this ILS, 29 laboratories participating in Pooled Fund Study TPF-5(178) performed dynamic modulus and flow number testing on specimens compacted from loose mix provided to each laboratory. As shown in Table 1, the 29 participating laboratories were divided into three groups based on region. Further description of this plan follows.

Target Air Void Content for Each Group

To provide more data for determining whether the specified air void tolerance of ±0.5 percent could be loosened to ±1.0 percent as recommended in NCHRP Project 09-29 without sacrificing data quality, the three groups of participating laboratories targeted different air void contents when preparing test specimens. Groups 1, 2 and 3 were asked to target 6 ± 0.5 percent, 7 ± 0.5 percent, and 8 ± 0.5 percent air voids with their test specimens, respectively. The final dynamic modulus and flow number test results were analyzed to determine if the air voids had significant and systematic effects on the final test results for the two tests.

TABLE 1 Experimental Plan

<table>
<tr><th>Description</th><th>Group 1</th><th>Group 2</th><th>Group 3</th></tr>
<tr><td rowspan="9">Participating laboratories</td><td>Georgia</td><td>New Hampshire</td><td>Wyoming</td></tr>
<tr><td>Alabama</td><td>Wisconsin</td><td>Kansas (x2)</td></tr>
<tr><td>Florida</td><td>Connecticut (x2)</td><td>Oregon</td></tr>
<tr><td>Kentucky</td><td>New York</td><td>Colorado</td></tr>
<tr><td>North Carolina</td><td>Maine</td><td>Nevada</td></tr>
<tr><td>Tennessee</td><td>Maryland</td><td>Utah</td></tr>
<tr><td>Virginia</td><td>New Jersey</td><td>Illinois</td></tr>
<tr><td>Puerto Rico</td><td>Pennsylvania</td><td>FHWA - CFL</td></tr>
<tr><td>Asphalt Institute</td><td>Ontario</td><td>FHWA Mobile Lab</td></tr>
<tr><td>Target specimen air voids for each group</td><td>6 ± 0.5%</td><td>7 ± 0.5%</td><td>8 ± 0.5%</td></tr>
<tr><td>Samples of loose mix to each laboratory</td><td colspan="3">Total of 12 samples, for preparation according to PP 60-09
- 5 to determine mixture weight to hit target air voids
- 3 for Dynamic Modulus (E*) testing
- 4 for Flow Number (Fn) testing</td></tr>
<tr><td>E* testing parameters</td><td colspan="3">Unconfined according to TP 79-11 and PP 61-10</td></tr>
<tr><td>Fn testing parameters</td><td colspan="3">Unconfined with deviator stress = 600 kPa (87 psi) and contact stress = 30 kPa (4.35 psi), as recommended in NCHRP Project 09-33</td></tr>
<tr><td>Total number of loose mix samples</td><td colspan="3">9×12 + 10×12 + 10×12 = 348
(Plus 12 samples for determining mix properties and target air voids at NCAT and 90 more samples for labs that would need more samples, resulting in a total of 450 samples)</td></tr>
<tr><td>Expected total number of specimens tested</td><td colspan="3">9×7 + 10×7 + 10×7 = 203</td></tr>
</table>

Sampling and Preparation of Loose Mix

NCAT sampled a 12.5 mm NMAS Superpave mix in Iowa and reduced it to the sample sizes using the sample splitting system at the Iowa Department of Transportation. A design of this mix is included in Appendix A. The split samples were boxed and shipped to the participating laboratories. Other information, including instructions for reheating loose mix samples, mixture properties and estimated sample mass to meet the target air void content, as shown in Appendix B, was provided to the laboratories.

As shown in Table 1, 12 samples were sent to each participating laboratory, and each sample contained enough loose mix to produce one 175 mm tall gyratory-compacted specimen. From these 12 loose mix samples, 5 were used to verify what sample weight would produce the target specimen air voids for the compactor used for preparing AMPT specimens in each laboratory or to replace specimens that did not meet the air void tolerances. From the remaining 7 loose mix samples, each laboratory produced 3 AMPT specimens for dynamic modulus testing and 4 AMPT specimens for flow number testing.

It was recommended that each participating laboratory use another loose mix to conduct an air void uniformity check on its AMPT specimens according to the procedure provided in Appendix X2 of AASHTO PP 60-09 before preparing AMPT specimens for the ILS.

Dynamic Modulus

Each laboratory produced 3 AMPT specimens from the provided loose mix to perform the dynamic modulus test in the AMPT. Testing was performed in accordance with AASHTO TP 79-11 at the temperatures and frequencies recommended in AASHTO PP 61-10. A high temperature of 40°C was selected since the mix being tested had a base binder grade of PG 64-22. These temperatures and frequencies were listed in the instructions to participating laboratories shown in Appendix B. The testing was performed unconfined.

Flow Number

Each laboratory also produced 4 AMPT specimens to perform the flow number test in the AMPT. Testing was performed in accordance with AASHTO TP 79-11 using testing parameters developed in NCHRP Project 09-33 (600 kPa (87 psi) deviator stress, 30 kPa (4.35 psi) contact stress, unconfined). The test temperature was selected for the location (i.e., Story County, Iowa) where the mix was sampled using LTPPBind v3.1. The temperature was the 50 percent reliability high temperature at a depth of 20 mm into the pavement structure with no adjustment for traffic. The resulting target test temperature for this mixture was 51.5°C.

LABORATORY TESTING

A set of detailed instructions, included in Appendix B, adapted from NCHRP Project 09-29 (Bonaquist, 2011) was provided to each of the participating laboratories regarding the testing parameters for both the dynamic modulus and flow number tests. A digital data reporting form (EXCEL® format) was provided to the laboratories for a standardized data collection method. Upon completion of testing, the participating laboratories completed the standardized data reports and returned them with the AMPT output files to NCAT for compilation with the other results and data analysis.

Before testing started, FHWA and NCAT staff went over the instructions with the participating laboratories via a webinar. Questions and answers during the webinar were summarized and sent to the participants after the webinar. During the ILS, NCAT staff was available by phone or e-mail to answer any questions by the participating laboratories about the testing protocol.

TEST RESULTS AND ANALYSIS

Upon completion of testing, the participating laboratories submitted data files for AMPT specimen preparation, dynamic modulus testing and flow number testing for importing into a database. At the writing of this report, 22 of the 29 labs had submitted data. The database was then analyzed to answer the questions relevant to the objectives of this inter-laboratory study. Results of this analysis are summarized in this section.

Data Quality Check

Prior to being imported into the database, the data quality of the test results were reviewed. For all results, the data files were checked to ensure the test temperature was within the ±0.5°C range of the target testing temperature. For the dynamic modulus test results, the data quality statistics (Table 2 of AASHTO TP 79-11) were reviewed to ensure the test results were reasonable. If significant issues were noted, the participating labs were notified and given the opportunity to re-test the specimen(s) in question and resubmit data. Typical issues involved the temperature in the AMPT chamber drifting more than ±0.5°C away from the target and with data quality indicators being outside the recommended tolerances. Generally, the data quality from the participating labs was of good quality. A summary descriptive statistics for each of the dynamic modulus data quality indicators listed in Table 2 of AASHTO TP79-11 are given in APPENDIX E. Data with quality indicators outside the recommended tolerances were evaluated on a case-by-case basis to assess their effect on the variability of testing results prior to inclusion in the database.

Analysis Procedure

The analysis method was similar to the methodology used in the NCHRP Project 09-29 ILS (Bonaquist 2011) so that results of the two inter-laboratory studies can be compared. For this analysis, the dynamic modulus, phase angle, and flow number data provided by the participating labs were analyzed in accordance with ASTM E691, *Standard Practice for Conducting an Interlaboratory Study to Determine the Precision of a Test Method.* The data were analyzed to determine the repeatability (within-lab variation) and reproducibility (between-lab variation) statistics within each of the three target air void groupings. In other words, a separate set of repeatability and reproducibility statistics was generated for each of the three testing groups shown in Table 1. The repeatability and reproducibility statistics from these groups could then be evaluated for trends (in particular, the effect of air void content) and compared to the repeatability and reproducibility statistics generated during the NCHRP Project 09-29 ILS. Lower repeatability and reproducibility statistics mean more repeatable and reproducible test results. A summary of the analysis methodology is provided below.

The within-lab and between-lab standard deviations and coefficients of variation were calculated for dynamic modulus, phase angle, and flow number for each group using Equations 1 through 4. These calculations were originally performed on the entire dataset prior to an outlier analysis being performed. For each individual test results, k and h statistics were calculated using Equations 5 and 6, respectively. The k statistic is a measure of data consistency within a laboratory while the h statistic is a measure of between laboratory data consistency. These statistics were compared with critical values from ASTM E691 which are a function of the number of labs and number of replicates. These values varied for each of the three groups and are summarized in Tables 2 and 3 for dynamic modulus and flow number testing, respectively. Data points exceeding these critical values of h and k were further reviewed for reporting errors and quality issues. Data points with unexplained variation were then tested in accordance with the procedure outlined in ASTM E178 *Standard Practice for Dealing with Outlying Observations*. For this procedure, the T_n statistic was calculated using Equation 7. The T_n statistic was compared to the T-critical value at the 0.5 percent significance level. This T-critical value was

1.155 for Dynamic Modulus testing (three replicates) and 1.496 for flow number testing (four replicates). Outliers determined using Equation 7 were eliminated from the data set and the repeatability and reproducibility statistics for the entire dataset were recalculated. For the dynamic modulus test, only 25 in a database of 660 data points were removed either due to failing data quality indicators or failing the aforementioned statistical outlier test (less than 4%). For the flow number test, only one of 88 data points was removed due to failing the statistical outlier test.

$$s_r = \sqrt{\sum_1^p \frac{s^2}{p}} \quad (1)$$

$$s_r(\%) = \frac{s_r}{\bar{X}} * 100 \quad (2)$$

$$s_R = \sqrt{(s_x)^2 + (s_r)^2 \left(\frac{n-1}{n}\right)} \quad (3)$$

$$s_R(\%) = \frac{s_R}{\bar{X}} * 100 \quad (4)$$

$$k = \frac{s}{s_r} \quad (5)$$

$$h = \frac{(\bar{x} - \bar{X})}{s_x} \quad (6)$$

$$T_n = \frac{|x_n - \bar{x}|}{s} \quad (7)$$

where

s_r = repeatability standard deviation,
s = within-laboratory standard deviation,
p = number of laboratories in the inter-laboratory study,
s_r (%) = repeatability coefficient of variation,
$\bar{X}$ = average of the laboratory averages,
s_R = reproducibility standard deviation,
s_x = standard deviation of the laboratory averages,
n = number of tests in each laboratory,
s_R (%) = reproducibility coefficient of variation,
k = within-laboratory consistency statistic,
h = between-laboratory consistency statistic,
$\bar{x}$ = laboratory average,
T_n = test statistic,
x_n = most extreme value from the average.

TABLE 2 Critical *h* and *k* Statistics used in ILS Analysis – Dynamic Modulus Testing (3 Replicates)

Target Air Voids	Number of Labs	k-critical	h-critical
6%	6	1.98	1.92
7%	7	2.03	2.05
8%	9	2.09	2.23

TABLE 3 Critical *h* and *k* Statistics used in ILS Analysis – Flow Number Testing (4 Replicates)

Target Air Voids	Number of Labs	k-critical	h-critical
6%	6	1.84	1.92
7%	7	1.87	2.05
8%	9	1.92	2.23

Repeatability and Reproducibility of Dynamic Modulus and Phase Angle

Figures 1 and 2 show the repeatability and reproducibility coefficients of variation (COV) for the dynamic modulus data. The data are plotted for each of the three groups against the testing conditions (test temperature and loading frequency). Data from NCHRP Project 09-29 are included in these figures for comparison. These NCHRP Project 09-29 data are from the 12.5-mm SMA loose mix samples with a target air void content of 7 percent. The data in Figure 1 show Group 1 (6 percent target air voids) generally had the lowest repeatability COV. The data from Group 1 had comparable repeatability to the NCHRP Project 09-29 data. The data from Group 2 (7 percent target air voids) and Group 3 (8 percent target air voids) generally had higher repeatability values. Figure 2 shows Group 1 generally had the lowest reproducibility COV, followed by Group 2 and Group 3. The reproducibility COV for all three groups was generally at or below the values determined in NCHRP Project 09-29. Tables 4, 5 and 6 provide a summary of the dynamic modulus statistical analysis for Groups 1, 2 and 3, respectively.

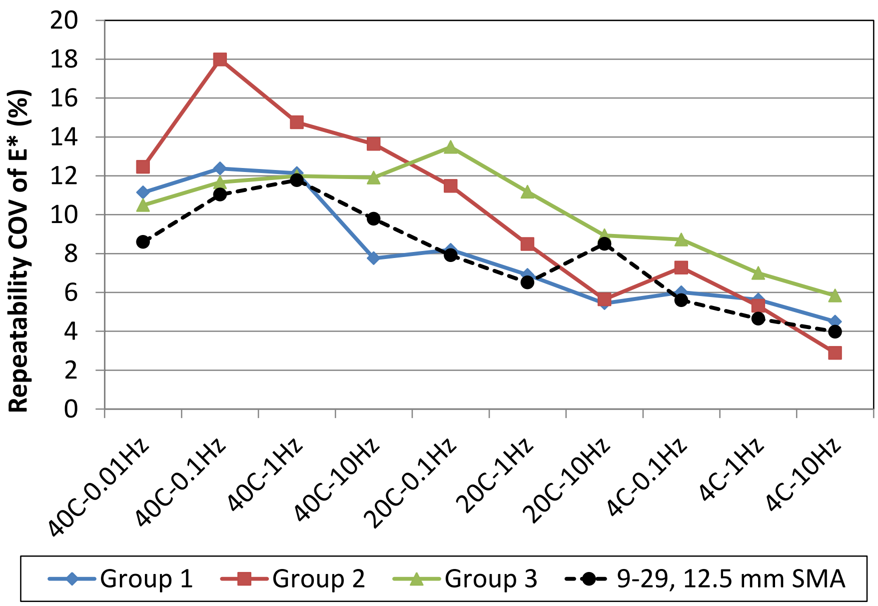


FIGURE 1 Repeatability COV (%) – Dynamic Modulus

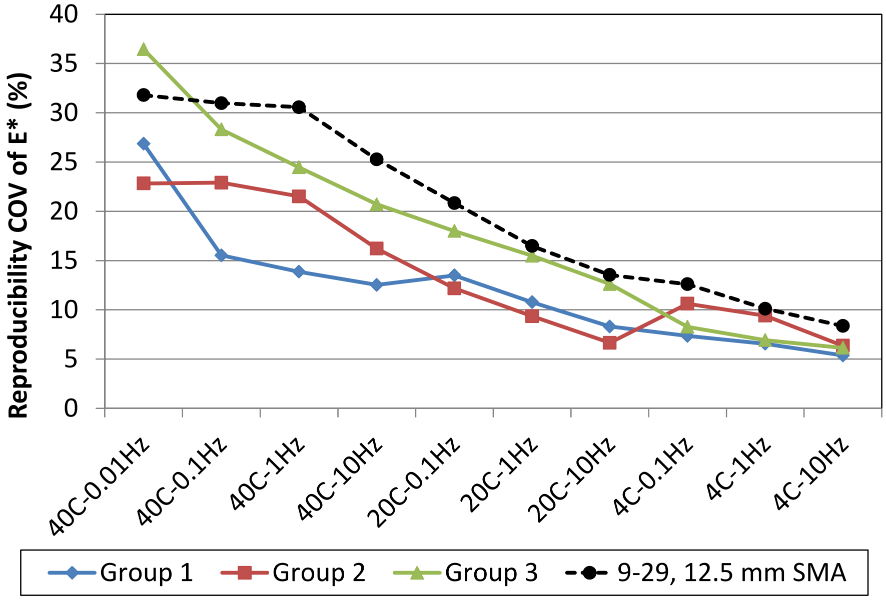


FIGURE 2 Reproducibility COV (%) – Dynamic Modulus

TABLE 4 Statistical Analysis Summary – Dynamic Modulus – Group 1 (6% Air Voids)

Temp (°C)	Freq (Hz)	Average E* (MPa)	s_r	s_r COV (%)	s_x	s_R	s_R COV (%)
40	0.01	261.4	29.1	11.1	66.1	70.2	26.9
40	0.1	519.6	64.3	12.4	61.3	80.7	15.5
40	1	1148.8	139.4	12.1	111.4	159.2	13.9
40	10	2485.3	192.8	7.8	268.4	311.2	12.5
20	0.1	3376.9	276.5	8.2	395.8	455.7	13.5
20	1	6026.8	416.0	6.9	553.4	649.3	10.8
20	10	9590.1	521.5	5.4	672.8	796.2	8.3
4	0.1	10741.9	645.1	6.0	587.2	788.8	7.3
4	1	14546.8	818.8	5.6	679.5	953.2	6.6
4	10	18147.4	815.9	4.5	710.2	973.7	5.4

TABLE 5 Statistical Analysis Summary – Dynamic Modulus – Group 2 (7% Air Voids)

Temp (°C)	Freq (Hz)	Average E* (MPa)	s_r	s_r COV (%)	s_x	s_R	s_R COV (%)
40	0.01	194.4	24.2	12.5	39.7	44.4	22.8
40	0.1	382.6	68.8	18.0	67.2	87.6	22.9
40	1	900.7	132.8	14.7	160.5	193.7	21.5
40	10	2027.6	276.5	13.6	238.9	328.7	16.2
20	0.1	2677.7	307.3	11.5	208.3	326.1	12.2
20	1	4949.0	419.8	8.5	311.0	462.8	9.4
20	10	8076.6	455.8	5.6	387.2	537.1	6.6
4	0.1	8786.3	639.3	7.3	773.4	933.1	10.6
4	1	12133.0	644.1	5.3	1012.6	1141.0	9.4
4	10	15607.6	450.4	2.9	922.5	993.1	6.4

TABLE 6 Statistical Analysis Summary – Dynamic Modulus – Group 3 (8% Air Voids)

Temp (°C)	Freq (Hz)	Average E* (MPa)	s_r	s_r COV (%)	s_x	s_R	s_R COV (%)
40	0.01	243.3	25.5	10.5	86.2	88.7	36.4
40	0.1	442.5	51.6	11.7	118.0	125.3	28.3
40	1	960.1	115.1	12.0	215.2	234.9	24.5
40	10	2120.4	252.5	11.9	387.8	439.2	20.7
20	0.1	2623.7	353.7	13.5	373.7	472.3	18.0
20	1	4834.1	540.3	11.2	604.5	748.3	15.5
20	10	7893.0	705.4	8.9	812.3	995.7	12.6
4	0.1	8490.0	740.2	8.7	357.1	702.0	8.3
4	1	11907.3	832.6	7.0	465.5	823.9	6.9
4	10	15378.7	897.5	5.8	595.3	944.1	6.1

Figures 3 and 4 show the repeatability and reproducibility standard deviations for the phase angle data. Similar trends were noted with the phase angle data shown in Figures 3 and 4 as with the dynamic modulus data shown in Figures 1 and 2. The data from Group 1 (6 percent target air voids) had comparable repeatability standard deviations to the NCHRP Project 09-29 data (Figure 3), with the data from Groups 2 and 3 generally having higher repeatability values. Figure 4 shows Group 1 generally had the lowest reproducibility, followed by Groups 2 and 3. The reproducibility for all three groups was generally at or below the values determined in NCHRP Project 09-29. Tables 7, 8 and 9 provide a summary of the phase angle statistical analysis for Groups 1, 2 and 3, respectively.

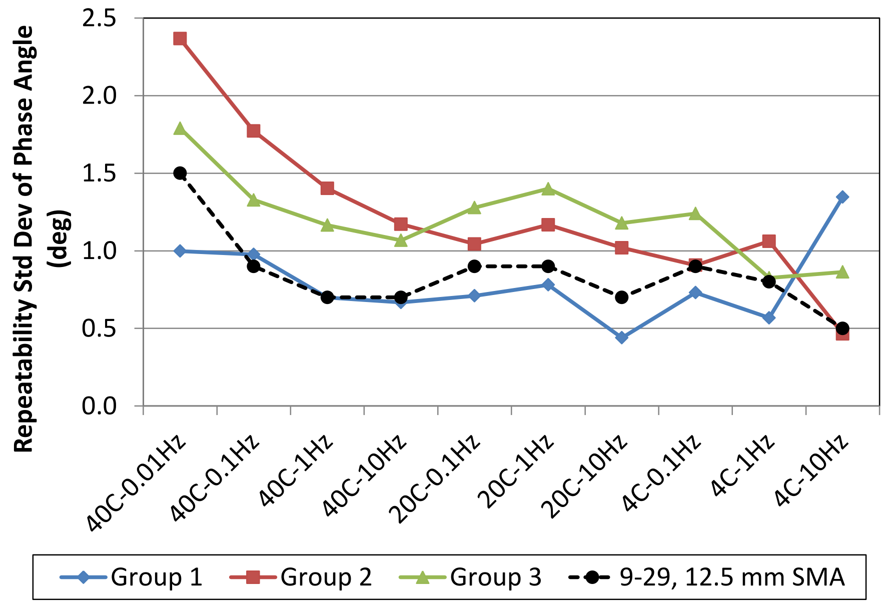


FIGURE 3 Repeatability Standard Deviation – Phase Angle

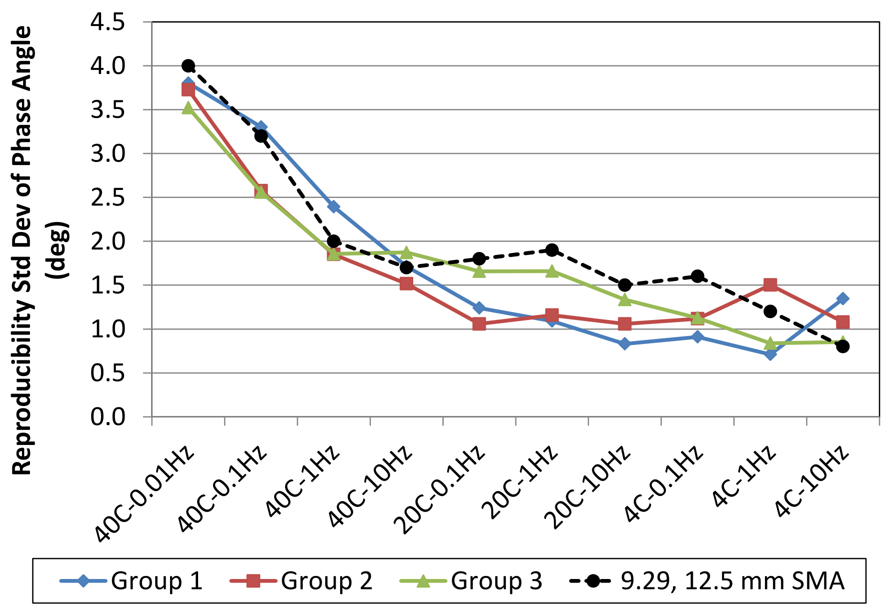


FIGURE 4 Reproducibility Standard Deviation – Phase Angle

TABLE 7 Statistical Analysis Summary – Phase Angle – Group 1 (6% Air Voids)

Temp (°C)	Freq (Hz)	Phase Angle (Deg)	s_r	s_r COV (%)	s_x	s_R	s_R COV (%)
40	0.01	24.0	1.0	4.2	3.7	3.8	15.8
40	0.1	29.5	1.0	3.3	3.2	3.3	11.2
40	1	32.6	0.7	2.1	2.3	2.4	7.4
40	10	31.7	0.7	2.1	1.6	1.7	5.4
20	0.1	27.8	0.7	2.6	1.1	1.2	4.5
20	1	22.5	0.8	3.5	0.9	1.1	4.8
20	10	17.1	0.4	2.6	0.7	0.8	4.9
4	0.1	15.0	0.7	4.9	0.7	0.9	6.1
4	1	11.1	0.6	5.1	0.5	0.7	6.4
4	10	9.1	1.3	14.8	0.8	1.3	14.7

TABLE 8 Statistical Analysis Summary – Phase Angle – Group 2 (7% Air Voids)

Temp (°C)	Freq (Hz)	Phase Angle (Deg)	s_r	s_r COV (%)	s_x	s_R	s_R COV (%)
40	0.01	23.1	2.4	10.2	3.2	3.7	16.1
40	0.1	29.0	1.8	6.1	2.1	2.6	8.9
40	1	33.2	1.4	4.2	1.5	1.9	5.6
40	10	33.7	1.2	3.5	1.2	1.5	4.5
20	0.1	29.4	1.0	3.5	0.6	1.1	3.6
20	1	24.2	1.2	4.8	0.7	1.2	4.8
20	10	18.7	1.0	5.5	0.7	1.1	5.7
4	0.1	16.3	0.9	5.6	0.8	1.1	6.8
4	1	12.4	1.1	8.6	1.2	1.5	12.1
4	10	10.0	0.5	4.6	1.0	1.1	10.8

TABLE 9 Statistical Analysis Summary – Phase Angle – Group 3 (8% Air Voids)

Temp (°C)	Freq (Hz)	Phase Angle (Deg)	s_r	s_r COV (%)	s_x	s_R	s_R COV (%)
40	0.01	20.0	1.8	9.0	3.2	3.5	17.6
40	0.1	26.4	1.3	5.0	2.3	2.6	9.7
40	1	30.7	1.2	3.8	1.6	1.9	6.0
40	10	31.4	1.1	3.4	1.7	1.9	6.0
20	0.1	28.9	1.3	4.4	1.3	1.7	5.7
20	1	24.0	1.4	5.8	1.2	1.7	6.9
20	10	18.6	1.2	6.3	0.9	1.3	7.2
4	0.1	16.5	1.2	7.5	0.5	1.1	6.8
4	1	12.3	0.8	6.7	0.5	0.8	6.8
4	10	9.4	0.9	9.2	0.5	0.9	9.1

In summary, for both dynamic modulus and phase angle, Group 1 (6 percent target air voids) generally had the lowest repeatability and reproducibility statistics. In terms of repeatability, the majority of the data was either at or above the values obtained in the NCHRP Project 09-29 ILS. This makes sense given the majority of the labs in the NCHRP Project 09-29 ILS were experienced users while many of the participating labs in the current ILS were just beginning to use the AMPT. In terms of reproducibility, the majority of the data was either at or below the values obtained in the NCHRP Project 09-29 ILS. This may be a result of the emphasis on the consistency in specimen preparation in this pooled-fund ILS. In addition, each of the participating labs in the pooled-fund ILS had received some uniform training from both the manufacturer and through the NHI AMPT training course, which may help improve the consistency in specimen preparation and testing between different laboratories.

Repeatability and Reproducibility of Flow Number

Figure 5 shows the repeatability and reproducibility coefficients of variation for the Francken Flow Number using the NCHRP Project 09-33 recommended test protocol for each group versus that of the data obtained in the NCHRP Project 09-29 ILS for unconfined flow number. A statistical summary of the data is provided in Table 10. The data showed significant improvements in both repeatability and reproducibility for each of the three groups for flow number versus the data obtained during the NCHRP Project 09-29 ILS. Figure 6 shows the coefficients of variation for each of the 22 participating labs whose data were included in this analysis. This value is based on four replicates. AASHTO TP 79-13 states the repeatability coefficient of variation for the flow number should be less than 43.1 percent for a 12.5 mm NMAS mix. The data from each of the 22 participating labs fell below this threshold. Given that many of the participating laboratories in this ILS ran the flow number test for the first time, both the repeatability and reproducibility values were encouraging.

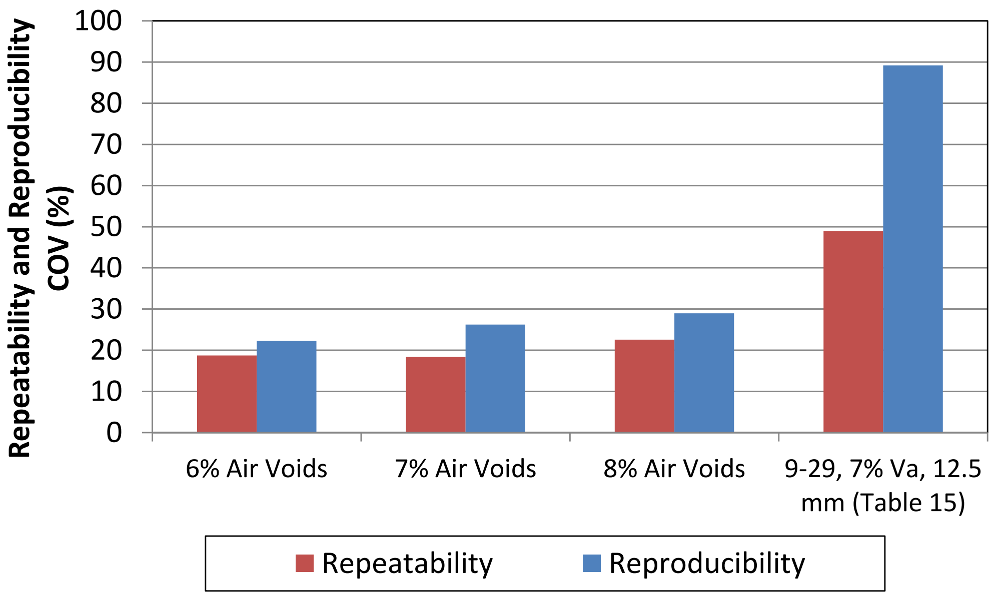


FIGURE 5 Repeatability and Reproducibility COV (%) – Flow Number

TABLE 10 Statistical Analysis Summary – Flow Number

Target Air Void Level (%)	Average Flow Number (Cycles)	s_r	s_r COV (%)	s_x	s_R	s_R COV (%)
6	339.5	63.6	18.7	51.7	75.6	22.3
7	211.1	38.8	18.4	44.0	55.4	26.2
8	145.0	32.7	22.6	31.1	42.0	29.0
NCHRP 09-29, 7% V_a, 12.5 mm (Table 15)			49.0			89.2

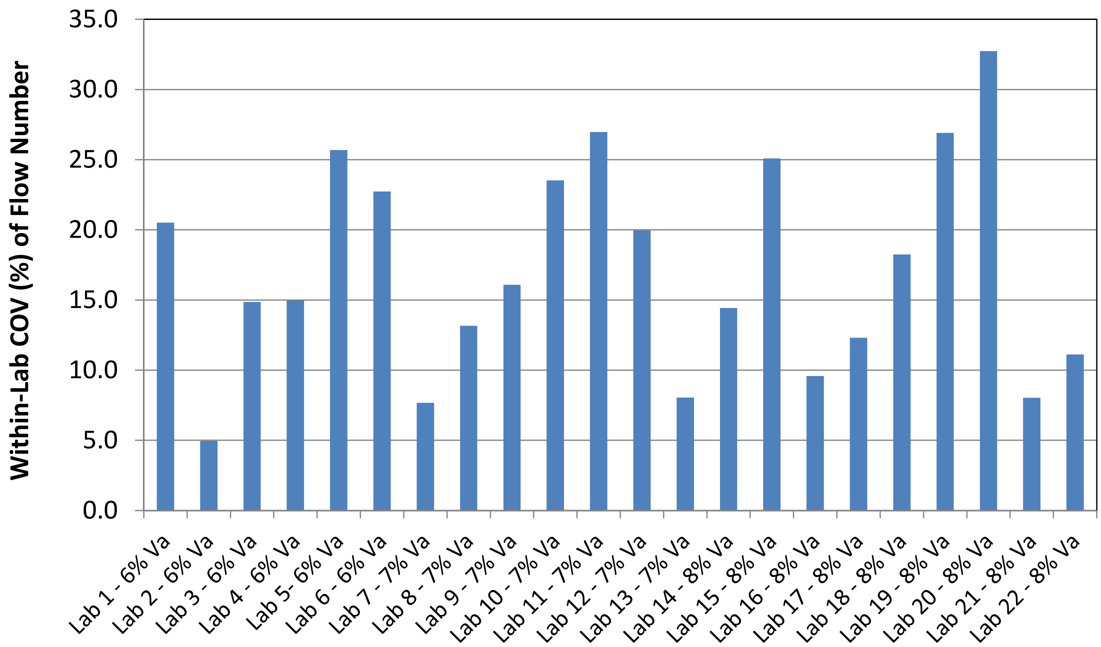


FIGURE 6 Within-Lab Flow Number COV(%) – Individual Laboratories

Effect of Air Voids on Dynamic Modulus Test Results

Figure 7 shows the average dynamic modulus values for each of the three testing groups across the full range of tested temperatures and frequencies. The plots show the data from the 7 percent and 8 percent air voids groups are virtually identical except for the data point at 40°C and 0.01 Hz. The dynamic modulus data from the 6 percent air voids group are consistently stiffer than those of the other two groups across the full range of tested temperatures and frequencies. To examine this trend in more detail, the raw data were analyzed for each combination of testing temperatures and frequencies.

Figures 8, 9, and 10 graphically examine the dynamic modulus data versus specimen air voids at the 4°C, 20°C, and 40°C test temperatures, respectively. Each of these plots contains a data series for the individual testing frequencies, on which a linear regression was performed. A summary of regression analysis statistics is provided in Table 11, and detailed regression analysis results are included in Appendix C.

For the 4°C test temperature (Figure 8), some correlation was seen between air voids and dynamic modulus, with the R^2 values for each series being approximately 0.5. The data showed dynamic modulus decreasing with increasing sample air voids, but with significant scatter in the data. At 20°C (Figure 9), the correlation still existed but was notably weaker (R^2 values around 0.35 to 0.4). Finally, at 40°C (Figure 10), little to no correlation was noted between dynamic modulus and sample air voids (R^2 values of 0.16 or less). A negative slope value was seen for each of the ten data series, but the correlation between sample air voids and dynamic modulus grew progressively weaker as the magnitude of the dynamic modulus decreased. Based on the results of statistical tests (Table 11), the effect of air voids on E* test results is statistically significant ($\alpha = 0.05$) at all test temperatures and frequencies, except at 40°C and 0.01 Hz. Based on the R^2 values shown in Table 11, up to approximately 50% of the variability of E* results in this study can be explained by the variability of specimen air voids, and the effect of specimen air voids is much less on E* determined at higher temperatures and lower frequencies.

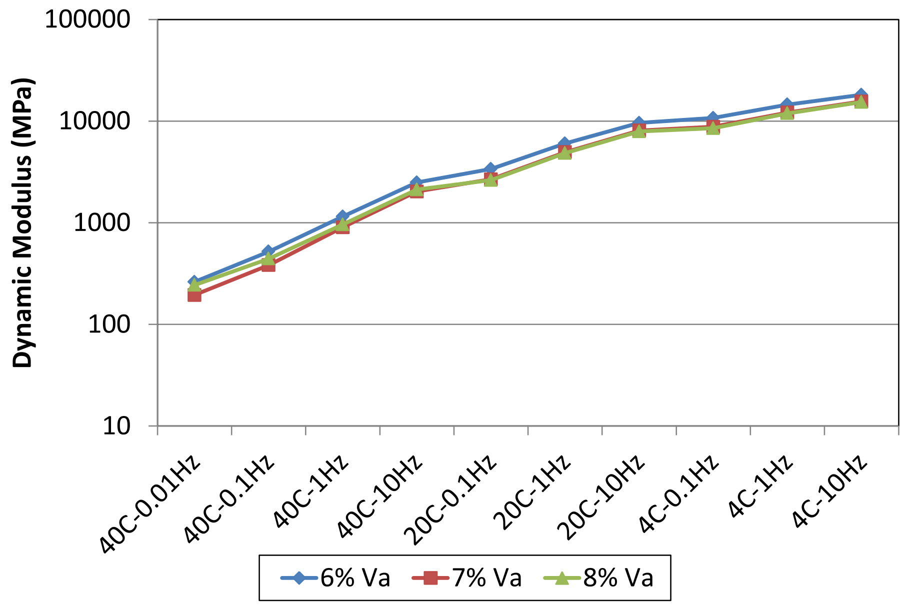


FIGURE 7 Average dynamic modulus values – Three air void levels

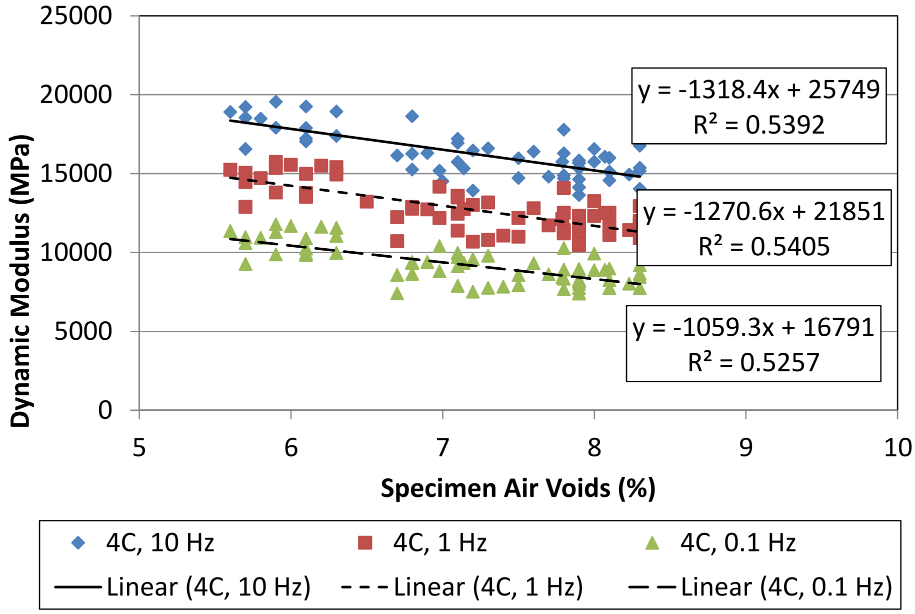


FIGURE 8 Dynamic modulus versus specimen air voids at 4°C

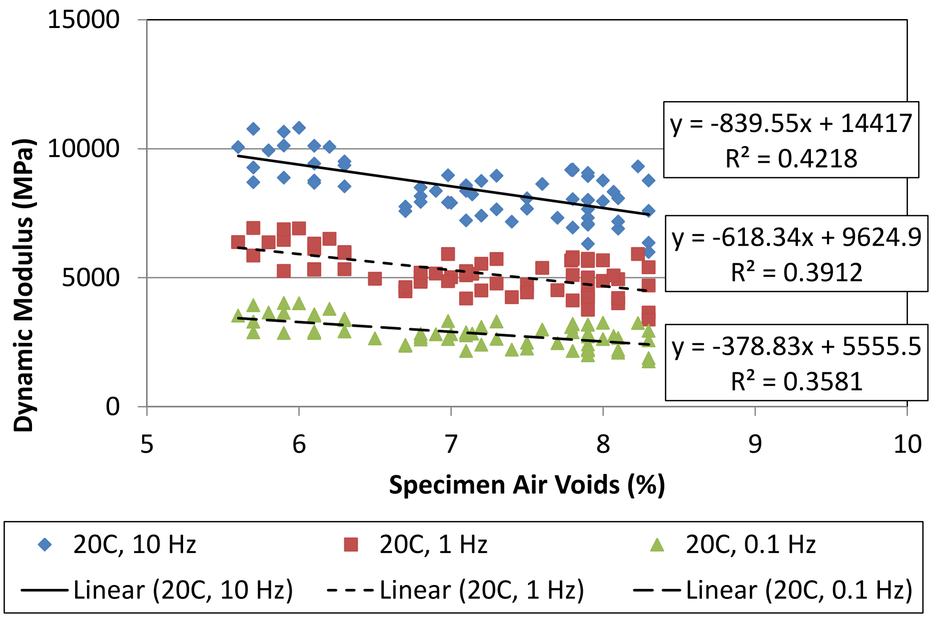


FIGURE 9 Dynamic modulus versus specimen air voids at 20°C

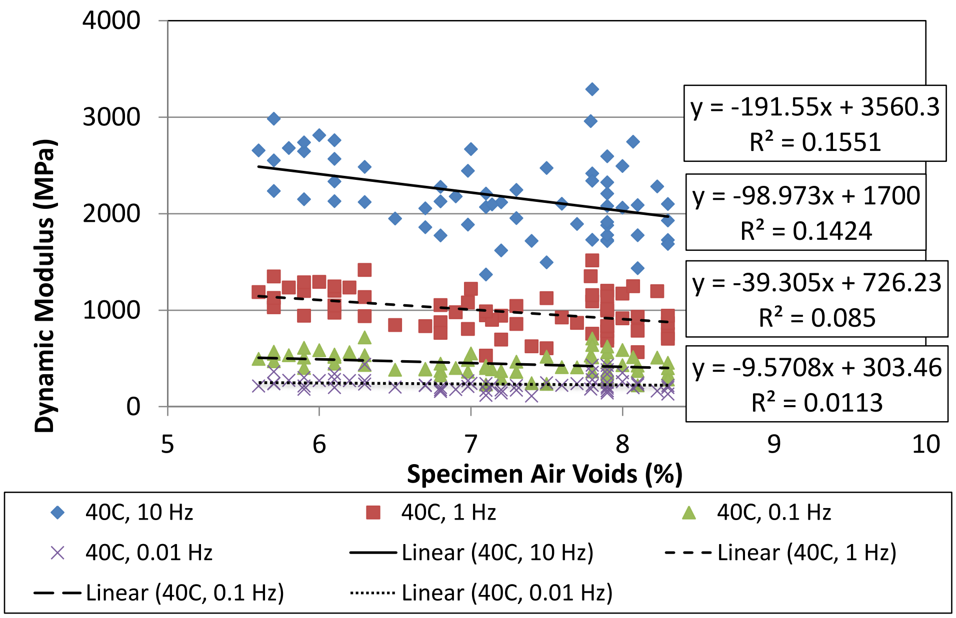


FIGURE 10 Dynamic modulus versus specimen air voids at 40°C

TABLE 11 Summary of Regression Analysis Statistics

Temp (°C)	Freq (Hz)	R^2	Adj. R^2	P-Value	Significant at α = 0.05?
40	0.01	1.1%	0.0%	0.415	No
40	0.1	8.5%	7.0%	0.018	Yes
40	1	14.2%	12.9%	0.002	Yes
40	10	15.5%	14.1%	0.001	Yes
20	0.1	35.8%	34.8%	< 0.001	Yes
20	1	39.1%	38.2%	< 0.001	Yes
20	10	42.2%	41.3%	< 0.001	Yes
4	0.1	52.6%	51.8%	< 0.001	Yes
4	1	54.0%	53.3%	< 0.001	Yes
4	10	53.9%	53.1%	< 0.001	Yes

Effect of Air Voids on Flow Number Test Results

Figure 11 plots the Francken Flow Number values versus specimen air voids for all of the flow number specimens tested during the ILS. A detailed statistical regression analysis is included in Appendix D. The analysis showed a good fit (R^2 = 0.7) between flow number and specimen air voids. The analysis also suggests that the linear relationship is significant (p-value = 0.000 for both t-test and F-test). The trendline has a slope of -95.3 for these data, meaning that every percent increase in air voids causes the average flow number to be reduced by approximately 95 cycles. The results of this analysis suggest that the effect of air voids on the Fn test results is more significant than on the E* test results.

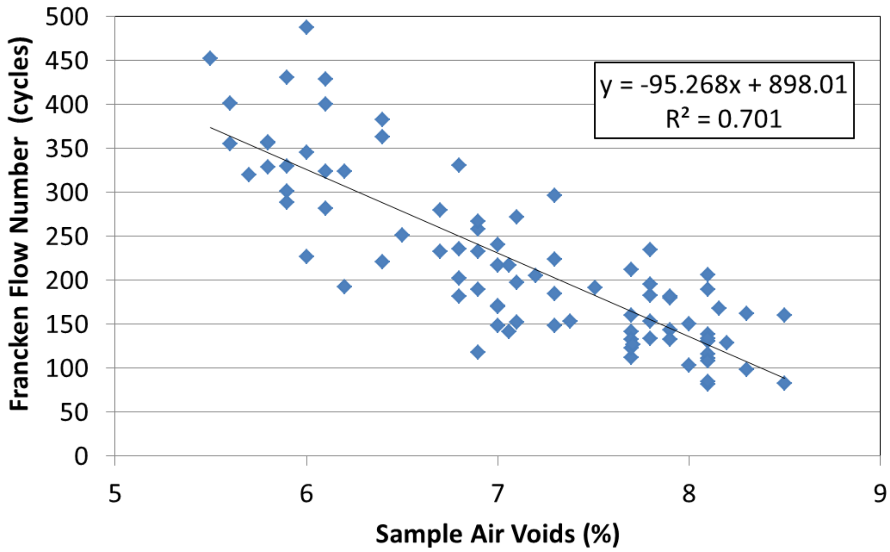


FIGURE 11 Francken Flow Number versus sample air voids (%) – All data

Effect of Other Factors on Dynamic Modulus and Flow Number Test Results

All of the participating labs had representatives at the NHI AMPT training course and received additional training on the use of their machine from a representative of the machine manufacturer. However, the majority of the participating labs were running the machine and producing usable data for the first time as a result of this study. This is in contrast with the NCHRP Project 09-29 ILS where the participating labs consisted of experienced users but with no centralized formal training.

In general, data from the participating labs was of good quality. If issues were noted, the labs were notified and often were able to correct the issues and resubmit their data. The biggest data quality issue involved the dynamic modulus testing at 4°C and 10 Hz. In two of the labs (one using an Interlaken and one using an IPC Global AMPT), this mixture was stiffer than the machine's load cell was capable of measuring at the coldest temperature and fastest loading frequency. This issue was only noted in labs compacting specimens to a target of 6% air voids. These issues caused a 'plateau' of the load measurement where a square wave was noted instead of a smooth sinusoidal curve (example shown in Figure 12). In both labs, the AMPT reached loads in excess of the maximum capacity of the load cell (13.5 kN). For the samples where this phenomenon was noted the data were removed from the overall database. This issue only occurred at one temperature and frequency combination, and the dynamic modulus data from four total samples was removed because of it.

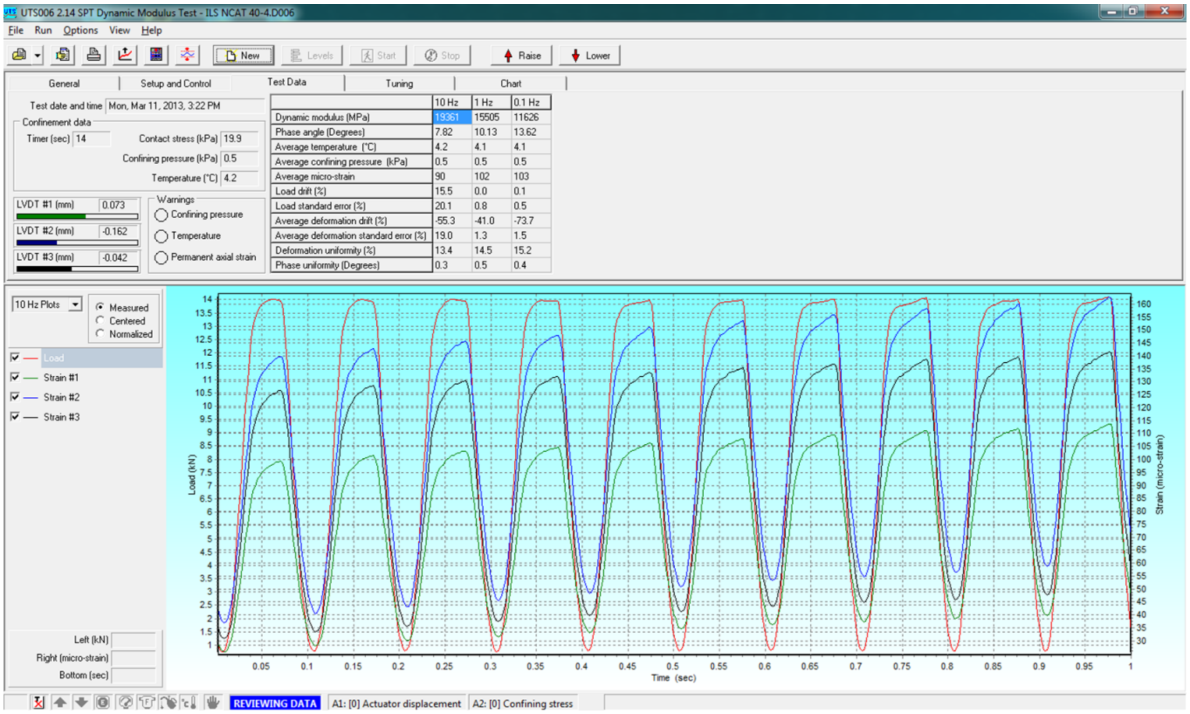


FIGURE 12 Example of actuator reaching maximum load during dynamic modulus testing

CONCLUSIONS

Twenty-nine laboratories received asphalt mixture for AMPT testing as part of this study under Pooled Fund Study TPF-5(178). For the pooled-fund inter-laboratory study (ILS), these labs were requested to perform dynamic modulus and flow number testing on specimens produced from the provided loose plant-produced mix. These labs were subdivided into three groups, each targeting a different air void level on their final prepared AMPT specimens. Groups 1, 2, and 3 targeted 6, 7, and 8 percent air voids, respectively. Each group targeted ± 0.5 percent air voids on their specimens. One of the primary objectives of the ILS was to encourage labs to use and produce data with their AMPT units. Of these 29 labs, 22 labs submitted data for the ILS at the time of the writing of this report. In this regard, the ILS accomplished this objective.

The second objective of the ILS was to compare the repeatability (within-lab variability) and reproducibility (between-lab variability) statistics for both dynamic modulus and flow number to those obtained during the NCHRP Project 09-29 ILS.

- For both dynamic modulus and phase angle, Group 1 generally had the lowest repeatability and reproducibility statistics.
- The within-lab variability values of the pooled fund ILS for dynamic modulus and phase angle were generally at or above the values obtained during the NCHRP Project 09-29 ILS. This may be owed to the lower experience level of the ILS participating labs relative to the higher experience level of the NCHRP Project 09-29 ILS labs.
- For both dynamic modulus and phase angle, Group 1 generally had the lowest reproducibility COV, followed by Groups 2 and 3.
- In terms of reproducibility of dynamic modulus and phase angle data, the majority of the data was either at or below the values obtained in the NCHRP Project 09-29 ILS. This

may be because each of the participating labs followed a more consistent procedure for preparing test specimens in the pooled fund ILS and had received some uniform training from both the manufacturer and through the NHI AMPT training course.

- For flow number, the repeatability and reproducibility statistics for each of the three groups were significantly improved over the NCHRP Project 09-29 ILS values. It is not sure if the consistency in the specimen preparation and uniform training may play an important role in this improvement.

The third objective of this ILS was to gather data on the effect of specimen air voids on dynamic modulus and flow number data. Specifically, whether or not widening the typical specimen fabrication tolerance of ± 0.5 percent to ± 1.0 percent would negatively impact the variability of the test results. A typical specimen target air void content of 7.0 percent was used as the benchmark for this evaluation.

- The analysis results suggest that specimen air voids have a significant effect on both the dynamic modulus data, particularly at the 4°C and 20°C test temperatures, and flow number results. Specifically, up to approximately 50% of the variability of dynamic modulus results and approximately 70% of the variability of flow number data in this study can be explained by the variability of specimen air voids. In addition, a linear regression of the flow number data between 5.5 and 8.5 percent air voids showed a 1.0 percent increase in air void content would yield a flow number reduction of approximately 95 cycles. Thus, based on the analysis results, it is not possible to support loosening the specimen fabrication air void tolerances from ±0.5 percent to ±1.0 percent.

REFERENCES

Bonaquist, R. *Precision of the Dynamic Modulus and Flow Number Tests Conducted with the Asphalt Mixture Performance Tester*. NCHRP Report 702, TRB, Washington, D.C., 2011, pp. 200.

APPENDIX A DESIGN OF ASPHALT MIXTURE USED IN THE AMPT INTER-LABORATORY STUDY

Form 956 ver. 9.11

Iowa Department of Transportation

Highway Division - Office of Materials

HMA Gyratory Mix Design

Ndesign

County :	Story		Project : STP-069-5(95)--2C-85	Letting Date :	2/21/2012
Mix Size (in.) :	1/2	Type A	Contractor : MANATTS INC	Mix No. :	1BD12-033
Mix Type:	HMA 3M	L - 3	Design Life ESAL's : 3,000,000	Contract #:	85-0695-095
Intended Use :	Surface		Location : MP 119.65 - 125.74	Date:	06/25/12

From .04 Mile S. of 190th N. to .05 Mile S. of E-18

Aggregate	% in Mix	Source ID	Source Location	Beds	Gsb	%Abs	FAA
1/2 CRUSHED EC	12.0%	A85006	Ames Mine/Martin Marietta	28-39	2.598	2.44	47.0
3/4 CR GRAVEL	20.0%	A85510	Ames South/Hallett Materials Co		2.651	1.13	49.0
3/8 CL CHIP LC	9.0%	A85006	Ames Mine/Martin Marietta	47-49	2.680	0.44	47.0
MANF SAND LC	26.0%	A85006	Ames Mine/Martin Marietta	47-49	2.659	0.78	45.0
SAND	15.0%	A85510	Ames South/Hallett Materials Co		2.615	1.03	40.0
1/2 RAP	18.0%	IWY 30 WES 18% 1RAP11-005 (5.4 % AC)			2.605	2.00	44.1

Job Mix Formula - Combined Gradation (Sieve Size in.)

	1"	3/4"	1/2"	3/8"	#4	#8	#16	#30	#50	#100	#200
Upper Tolerance	100	100	98	89	67	49		22			5.6
	100	100	91	82	60	44	30	18	7.9	4.5	3.6 ← QC
Lower Tolerance	100	100	84	75	53	39		14			1.6

Asphalt Binder Source and Grade: BITUMINOUS MTLS PG 58-28

Gyratory Data

		JMF			
% Asphalt Binder	4.50	4.70	5.00	5.50	
Gmb @ N-Des.	2.388	2.392	2.399	2.428	
Max. Sp.Gr. (Gmm)	2.500	2.492	2.481	2.466	
% Gmm @ N- Initial	87.8	88.2	88.8	90.3	
%Gmm @ N-Max	96.7	97.2	97.9	99.7	
% Air Voids	4.5	4.0	3.3	1.5	
% VMA	13.5	13.5	13.5	13.0	
% VFA	66.9	70.4	75.6	88.1	
Film Thickness	9.14	9.62	10.33	11.36	
Filler Bit. Ratio	0.93	0.89	0.83	0.75	
Gsb	2.636	2.636	2.636	2.636	
Gse	2.681	2.683	2.681	2.686	
Pbe	3.88	4.08	4.38	4.82	
Pba	0.65	0.68	0.65	0.72	
% New Asphalt Binder	79.2	80.1	81.4	83.1	
Asphalt Binder Sp.Gr. @ 25c	1.025	1.025	1.025	1.025	
% Water Abs	1.28	1.28	1.28	1.28	
S.A. m^2 / Kg.	4.24	4.24	4.24	4.24	
% + 4 Type 4 Agg. Or Better	80.8	80.8	80.8	80.8	
% + 4 Type 2 or 3 Agg.	48.1	48.1	48.1	48.1	
% -4 Type 2	0.0	0.0	0.0	0.0	
Fineness Modulus of Type 2	0.0	0.0	0.0	0.0	
Angularity-method A	43	43	43	43	
% Flat & Elongated	0.4	0.4	0.4	0.4	
Sand Equivalent	91	91	91	91	
Aggregate Type	A	A	A	A	
% Crushed	81	81	81	81	

Number of Gyrations
N-Initial
7
N-Design
86
N-Max
134
Gsb for Angularity
Method A
2.631
Pba / %Abs Ratio
0.53
%Gmm @ N-Max
95.8
Mix Check
Excellent
Pb Range Check
1.00
RAM Check
OK
Specification Check
Comply
TSR Check
Not Required

Disposition : An asphalt content of 4.7% is recommended to start this project.

Data shown in 4.70% column is interpolated from test data.

The % ADD AC to start project is 3.8%

Comments :

Copies to : MANATTS INC

Mix Designer & Cert.# : CINDY DELA ROSA CI 722 Signed :

Form 955 ver. 9.11

Iowa Department of Transportation

Highway Division-Office of Materials

Proportion & Production Limits For Aggregates

County : Story   Project No.: STP-069-5(95)--2C-85   Date: 06/25/12

Project Location: From .04 Mile S. of 190th N. to .05 Mile S. of E-18   Mix Design No.: 1BD12-033

Contract Mix Tonnage: 10,065   Course: Surface   Mix Size (in.): 1/2

Contractor: MANATTS INC   Mix Type: HMA 3M   Design Life ESAL's 3,000,000

Material	Ident #	% in Mix	Producer & Location	Type (A or B)	Friction Type	Beds	Gsb	%Abs
1/2 CRUSHED EC	A85006	12.0%	Ames Mine/Martin Marietta	A	4	28-39	2.598	2.44
3/4 CR GRAVEL	A85510	20.0%	Ames South/Hallett Materials Co	A	3		2.651	1.13
3/8 CL CHIP LC	A85006	9.0%	Ames Mine/Martin Marietta	A	5	47-49	2.680	0.44
MANF SAND LC	A85006	26.0%	Ames Mine/Martin Marietta	A	5	47-49	2.659	0.78
SAND	A85510	15.0%	Ames South/Hallett Materials Co	A	4		2.615	1.03
1/2 RAP	VY 30 WE	18.0%	18% 1RAP11-005 (5.4 % AC)	A	3		2.605	2.00

Type and Source of Asphalt Binder: PG 58-28 BITUMINOUS MTLS

Individual Aggregates Sieve Analysis - % Passing (Target)

Material	1"	3/4"	1/2"	3/8"	#4	#8	#16	#30	#50	#100	#200
1/2 CRUSHED EC	100	100	92	72	32	22	17	13	11	9.5	7.5
3/4 CR GRAVEL	100	100	64	41	8.1	2.5	2.0	1.7	1.5	1.4	1.2
3/8 CL CHIP LC	100	100	100	91	25	3.5	2.5	1.6	1.5	1.3	1.0
MANF SAND LC	100	100	100	100	97	68	39	20	7.5	3.2	2.5
SAND	100	100	100	100	98	87	69	40	8.0	0.6	0.2
1/2 RAP	100	100	95	89	69	54	40	28	17	12	9.8

Preliminary Job Mix Formula Target Gradation

Upper Tolerance	100	100	98	89	67	49		22			5.6
Comb Grading	100	100	91	82	60	44	30	18	7.9	4.5	3.6
Lower Tolerance	100	100	84	75	53	39		14			1.6
S.A.sq. m/kg	Total	4.24		+0.41	0.25	0.36	0.50	0.52	0.48	0.56	1.18

Production Limits for Aggregates Approved by the Contractor & Producer.

Sieve Size in.	12.0% of mix 1/2 CRUSHED EC		20.0% of mix 3/4 CR GRAVEL		9.0% of mix 3/8 CL CHIP LC		26.0% of mix MANF SAND LC		15.0% of mix SAND		18.0% of mix 1/2 RAP	
	Min	Max	Min	Max	Min	Max	Min	Max	Min	Max	Min	Max
1"	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0		
3/4"	100.0	100.0	98.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0		
1/2"	90.0	100.0	57.0	71.0	100.0	100.0	100.0	100.0	100.0	100.0		
3/8"	68.0	80.0	34.0	48.0	88.0	98.0	100.0	100.0	98.0	100.0		
#4	28.0	38.0	1.1	15.1	18.0	32.0	92.0	100.0	91.0	100.0		
#8	16.0	24.0	0.0	7.5	0.0	6.0	63.0	73.0	82.0	92.0		
#30	8.0	15.0	0.0	5.7	0.0	3.0	15.0	23.0	36.0	44.0		
#200	4.5	8.5	0.0	3.2	0.0	1.5	0.0	2.5	0.0	2.2		

Comments:

Copies to: MANATTS INC

The above target gradations and production limits have been discussed with and agreed to by an authorized representative of the aggregate producer.

Signed: ______________________ Producer

Signed: ______________________ Contractor

Plant Mix

800241 - 6/07/12 ver 7.10 10/3/2012

IOWA DOT ASPHALT PAVING DAILY PLANT REPORT

10/4/12 8:14 AM

Project No.:	NHSX-030-5(240)--3H-85	Contractor:	MANATTS INC	Active Placement:	Surface (Travel Lane)
Contract ID:	85-0305-290	County:	Story	Mix Type:	3M Surface 1/2 L-3 (HMA)
Mix Design No.:	1BD12-033	Recycle Source:	18% 1RAP11-005 RAP (5.4 % AC)	Active Bid Item:	2303-0043503 3M Surf 1/2in L-3 (HMA)

Report No.: 18
Lab Voids Target: 4.0
Design Gyrations: 86

UNCOMPACTED MIXTURE

Hot Box I.D.	Date Sampled	Time	Station	Side	Sample (Tons)	Sublot (Tons)	G_{mb}	G_{mm}	Pa (%)	Limits (%)
CLD-HB-1	10/03/12	8:55 AM	2585+80	EB Rt	381.00	750.00	2.407	2.497	3.6	4.0 ± 1.0
CLD-HB-1	10/03/12	11:45 AM	2607+15	EB Rt	1,094.49	750.00	2.411	2.496	3.4	4.0 ± 1.0
CLD-HB-1	10/03/12	1:50 PM	2652+60	EB Rt	1,836.92	750.00	2.400	2.496	3.8	4.0 ± 1.0
CLD-HB-1	10/03/12	4:00 PM	2686+86	EB Rt	2,595.14	1,038.75	2.418	2.496	3.1	4.0 ± 1.0
					Contractor Average:		2.409	2.496	3.5	
					District Results for Box #CLD-HB-18A		2.389	2.493	4.2	
					Validation?		Yes	Yes		

COMPACTED MIXTURE — Cores

Core	Station	C.I. Reference	Wt Dry (g)	Wt in H2O (g)	Wt Wet (g)	Diff.	G_{mb}	% of Gmm	Pa (%)	Thickness (in.)
1	2549+20	1.8 WB Drv	1,629.1	925.8	1,631.8	706.0	2.308	92.5	7.5	1.80
2	2568+92	4.4 WB Drv	1,789.0	1,020.0	1,790.9	770.9	2.321	93.0	7.0	1.90
3	2601+35	5.8 WB Drv	1,734.0	984.9	1,735.9	751.0	2.309	92.5	7.5	1.90
4	2621+96	5.1 WB Drv	1,760.0	1,008.0	1,761.4	753.4	2.336	93.6	6.4	1.90
5	2631+51	1.8 WB Drv	1,831.1	1,038.8	1,833.5	794.7	2.304	92.3	7.7	2.00
6	2655+22	3.8 WB Drv	1,853.6	1,062.2	1,855.3	793.1	2.337	93.6	6.4	2.00
7	2668+65	8.3 WB Drv	1,782.0	1,017.0	1,783.7	766.7	2.324	93.1	6.9	1.90
8	2693+77	6.8 WB Drv	1,845.7	1,054.9	1,847.0	792.1	2.330	93.3	6.7	2.00

Course Placed:	Surface (Travel Lane)	Thickness QI:	3.38
Intended Lift Thickness:	1.75	Avg. Field Density:	2.321
Date Placed:	10/03/12	Avg. % of Gmm:	92.988
Test Date/By:	10/03/12 Moses Bomringer	Avg. % Field Voids:	7.01

Q.I. (lower) = [(0.966 x 2.496) − 2.321] / 0.013 = 6.74 → PWL (lower) = 100.0

Q.I. (upper) = [2.321 − (0.915 x 2.496)] / 0.013 = 2.86 → PWL (upper) = 100.0

PWL (total) = 100.0 + 100.0 − 100.0 = 100.0

Pay Factor = 1.040

Tons of Mix for PWL Field Voids Analysis (00.00 deducted) = 3,288.75 Field Voids Incentive = $4,854.20

275°F Lab

GRADATION (% Passing) ☐ Use DOT

Sieve	Specs	CLD-CF-18A			Avg	District
1 in.	100	100.0			100.0	
3/4 in.	100	100.0			100.0	
1/2 in.	84-98(91)	93.0			93.0	
3/8 in.	76-89(82)	85.0			85.0	
#4	53-67(60)	63.0			63.0	
*Dev	± 7.0	3.0			3.0	
#8	39-49(44)	46.0			46.0	
*Dev	± 5.0	2.0			2.0	
#16		33.0			33.0	
#30	14-22(18)	19.0			19.0	
*Dev	± 4.0	1.0			1.0	
#50		9.3			9.3	
#100		6.4			6.4	
#200	1.6-5.6(3.6)	4.3			4.3	
*Dev	± 2.0	0.7			0.7	
Gradation Compliance?		Yes			Yes	
DBR	0.6 - 1.4	1.06			1.06	
% +4 Type 4	80	87.3			87.3	
% +4 Type 3	45	51.9			51.9	
(+4/-4) Type	(25/0)	00.0/00.0			00.0/00.0	

Cold Feed Grad.

USE D.O.T. RESULTS (Enter an "X")

TEST STRIP (Enter an "X")

FILM THICKNESS (FT) (8.0-15.0)	
FT, µm	8.6
Price Adjustment	$0.00

Mix Unapproved (See IM 511A)	
VMA, %	13.0

QUANTITY FOR PAYMENT	
Mix Unit Price ($/ton)	$36.90
Binder Unit Price ($/ton)	$600.00
Tons of Mix on Road	3,288.75
Tons to Other Bid Item(s)	
Tons of Binder	159.01
Tons of Waste	60.85
Tons of Binder to Date	2,091.16
Tons of Mix to Date	8,071.07

TEMPERATURE, °F

Time	7:00	9:00	11:00	1:00	3:00	5:00	7:00	Spec	Comply?
Air Temp	41	60	69	75	77	78			
Binder Temp	300	300	300	300	300	300		260-330 °F	Yes
Plant Temp	329	328	326	328	327	326		225-330 °F	Yes
Mat Temp	280	288	285	288	283	281		225-330 °F	Yes

~285°F MAT

☐ Restart after mandatory shutdown ☐ Break Down ☐ Rate Out

Mix Change Information (when changes are made to start the day, identify them on previous day's report):

Target Change	New Target	Tons	Agg	Initial %	New %	Agg	Initial	New %
		1,760	Agg 1	12	9			
		1,760	Agg 4	9	12			

switched Agg 1 & 4 % @ 1760 tons

Comments:

BINDER

	Target	Actual	Spec	Comply?
% Added Binder	3.87	3.89	N/A	
% Total Binder	4.80	4.83	4.50-5.10	Yes
% RAP	18.00	18.21%	≤100%	Yes
% RAS				
% Binder Replacement	20.25%	19.54%	≤ 30%	Yes
PG Grade	64-22		64-22	Yes
Gb: 1.03230	Gsb: 2.636		Pbe (%): 4.08	

?. ✓

PLACEMENT RECORD

From MP	To MP	Lane	Width (ft)
2546+25	2727+75	WB/EB Drive Ln	16

Certified Tech: CINDY DELA ROSA Cert. No CI 722
Certified Tech: JAMIE BOUGHNER Cert. No CI 408

Distribution: ___ Dist. Materials ___ Proj. Engineer ___ Contractor

APPENDIX B INSTRUCTIONS TO PARTICIPANTS OF THE AMPT INTER-LABORATORY STUDY

1. Device Verification/Calibration

a) Please provide information regarding the equipment used for this study and the calibration/verification of that equipment. A brief form for this data is provided in the Excel file. These data include:
    a. AMPT
        i. Brand of AMPT
        ii. Date of last calibration
        iii. Company that performed calibration
    b. Gyratory Compactor
        i. Make and model
        ii. Date of last calibration/verification
        iii. Calibrated internal angle
    c. Mix Oven
        i. Model

2. Sample Preparation

a) Each laboratory will receive 12 individual boxes of loose mix. Each box should have enough mix to produce one AMPT specimen (AASHTO PP 60-09). From these 12 samples, up to five mix samples can be used for the trial and error process of determining the appropriate mass required to produce an AMPT specimen at the target air void content. Details on this process follow. It is required that each lab prepare 7 AMPT specimens at the target air void content.
    a. Weigh the individual sample boxes prior to heating to ensure they contain enough mix to produce an AMPT specimen at the appropriate target weight. The average weight of the empty box is 215 grams.
    b. If a sample box does not contain sufficient mix, it may have to be combined with another sample box and split out (AASHTO R 47) to get the required amount of mix.
        i. It is preferred the blended and split samples be used for the trial and error process of determining sample air voids rather than for testing, if possible.

b) The target compaction temperature for the samples is 275°F (135°C). The G_{mm} is 2.492.

c) The first step in the specimen preparation process is to determine the required mass of loose mix for producing specimens at the target air voids.
    a. As initial guidance, Table B.1 provides the mixture masses used by NCAT to produce 175 mm tall gyratory-compacted samples to the target air void content. These weights may vary from lab to lab depending on compaction equipment. **These values should only be used as a starting point in the trial and error process required to produce samples with the correct air void content.**

TABLE B.1 Mixture Masses Used by NCAT to Achieve Target Air Voids for 175 mm Sample

Target Air Void Content	Sample Mass for Trial Sample (g)
6.0 ± 0.5	7040
7.0 ± 0.5	6970
8.0 ± 0.5	6900

d) Remove one sample of loose mix (a single cardboard box) from the shipping packages. Remove the clear packing tape from the top of the box (the tape on the bottom is heat resistant). Place this box in an oven set to 290°F (143°C) for 2 hours to bring the mix up to a temperature where it is sufficiently workable.

e) After heating for 2 hours, transfer the mix from the cardboard box to a metal pan. Place mix back in oven.
    a. Weigh out the mix required for the specimen at this point (Table B.1 for the first trial specimen). Set excess mix aside.

f) Continue heating the mix until it reaches the target compaction temperature of 275°F (135°C).
    a. Insert a thermometer into the center of the mix and record the mix temperature to verify it reaches the compaction temperature.
    b. Samples should only be heated the minimum amount of time to reach the compaction temperature of 275°F (135°C). **DO NOT LEAVE MIX IN THE OVENS OVERNIGHT UNDER ANY CIRCUMSTANCES.**
    c. Record the time required to heat the sample to the compaction temperature in the provided spreadsheet under the 'specimen information' tab.

g) Remove the heated sample, charge the pre-heated compaction mold using proper procedures, and compact the trial sample to the target height. Extrude the compacted sample from the mold and place under a fan.

h) Cool the compacted sample for a minimum of three hours under a fan (overnight is preferred).

i) Determine the bulk specific gravity of the compacted sample according to AASHTO T 166-12.

j) Core and cut the compacted sample into an AMPT specimen using the required tolerances from AASHTO PP 60-09. These tolerances are summarized in Table B.2. Adherence to these testing parameters is vital to ensuring valid test data.

TABLE B.2 AMPT Sample Fabrication Tolerances (AASHTO PP 60-11)

Parameter	Acceptable Tolerance
Air Void Tolerance	Target ± 0.5%
Average Sample Diameter	100 to 104 mm*
Standard Deviation of Sample Diameter	≤ 0.5 mm
Sample Height	147.5 to 152.5 mm
End Flatness	≤ 0.5 mm
End Perpendicularity	≤ 1.0 mm

* Tolerance expanded from current PP60-09 based on recommendation from Asphalt Mixture ETG.

k) After the sample is cut, determine the submerged weight and SSD weights in accordance with AASHTO T 166-12. Place the sample under a fan to dry to a constant mass. This will speed production since the samples don't have to be dried out twice (see AASHTO PP 60-09 Section 9.7.2).
    a. The fan drying process typically takes a minimum of two days. Check the sample mass a minimum of four hours apart to ensure the sample mass has changed less than 0.1 percent.
    b. Alternatively, a vacuum drying device operated at room temperature can be used to speed the drying process.
    c. Record the method of drying used in the provided spreadsheet.

l) Determine the dry mass and calculate the air voids of the final cut AMPT specimen.

m) If the sample air voids for the trial sample are within ± 0.3 percent of the target, the compaction mass is satisfactory to produce specimens at the target air void content. This sample mass can now be used to produce the AMPT specimens required for testing and proceed with Step 2.o below.

n) If the trial specimen air voids are outside the target ± 0.3 percent range, compute the adjusted sample mass using the equation below and repeat Steps 2.d through 2.k until the air void requirement in Step 2.m is satisfied.

$$Adjusted\ Mass\ (g) = \left[\frac{100 - Target\ Air\ Voids\ (\%)}{100 - Trial\ Specimen\ Air\ Voids\ (\%)}\right] * Mass\ of\ Trial\ Specimen\ (g)$$

o) The next step in the specimen preparation process is to produce test specimens using the required mass of mixture determined in Step 2.m. Repeat Steps 2.d through 2.l to produce samples at the target air void content.
    a. It is recommended to produce samples in batches of three. In this way, if there is a problem with one production run of samples it will be limited to a smaller number of samples.
    b. In Step 2.d, place three loose mix samples in the oven at 15-minute intervals. Then proceed with the remaining fabrication steps. Each sample should be compacted after it has been heated the minimum amount of time as discussed in Step 2.f.

p) Prepare all the remaining specimens and select seven specimens that meet the target air voids. Three will be for dynamic modulus, and four will be for flow number.

q) Complete the 'Specimen Information' tab in the provided spreadsheet.

3. Dynamic Modulus Testing

a) The dynamic modulus test shall be run unconfined at the temperatures and frequencies listed in Table B.3.

b) Unconfined tests shall be performed without a membrane on the specimen.

c) Either Teflon or 'Greased Latex' friction reducers may be used, so long as one type of reducer is used to test all the dynamic modulus specimens and all the reducers used are fabricated in accordance with the requirements in AASHTO PP 79-11. A new set of friction reducers should be used for each specimen tested at each temperature (9 sets total).

TABLE B.3 Dynamic Modulus Testing Temperatures and Frequencies (AASHTO PP 61-10)

Temperature	Frequency (Hz)	Temperature	Frequency (Hz)	Temperature	Frequency (Hz)
4°C	10	20°C	10	40°C	10
	1		1		1
	0.1		0.1		0.1
					0.01

d) Ensure all samples are tested with the upper loading platen in the ‘free to rotate’ configuration.
   a. Utilize the ball in the upper platen for the IPC device.
   b. Utilize the rounded top plate for the Interlaken device.

e) Perform the tests on different temperatures in the order of lowest to highest (first run all 4°C tests, then all 20°C tests, and finally all 40°C tests). The frequency sweep shall be performed on samples from fastest to slowest (highest number to lowest number in Hz). All three specimens should be tested at the same temperature prior to moving on to the next temperature.
   a. Temperature conditioning of specimens shall be performed in accordance with the recommendations in AASHTO PP 79-11.
   b. Fabricate a dummy specimen using one of the trial and error specimens that are not used for AMPT testing (Guidance for fabricating dummy specimen in NHI AMPT Training Course – Module 4). Condition the dummy specimen alongside testing specimens. Temperature readings from the dummy specimen will be used to determine when the testing specimens have reached the target testing specimen.
      i. The temperature of the conditioning chamber should be verified with a calibrated thermometer at each test temperature.
      ii. Either an air or water conditioning chamber may be used, so long as the conditioning temperatures are verified. However, if water is used, care **MUST** be taken not to get the samples wet.
         a. Note the type of conditioning chamber used in the provided spreadsheet.
         b. Note the average time required to condition the samples in the provided spreadsheet.
      iii. Condition the testing specimens the minimum amount of time required for them to reach the desired testing temperature.

f) Check data quality on all three specimens prior to proceeding to the next test temperature. Guidance on acceptable data quality can be found in Table B.4 and is fully summarized in AASHTO TP 79-11.
   a. Additionally, the provided data template utilizes conditional formatting so that out of tolerance data quality statistics are highlighted for further review.

   b. If using the IPC device, utilize the compensating springs (if provided) for the high testing temperature to prevent reverse deformation drift. These may not be required on some newer model units. Verify this with the manufacturer before testing at the high temperature.

g) Exported data shall be copied/pasted into the data summary file provided (the attached Excel file).

TABLE B.4 Data Quality Limits for Dynamic Modulus Test (AASHTO TP 79-11)

Data Quality Statistic	Limit
Deformation Drift	No Limit in Direction of Applied Load
Peak-to-Peak Strain	75 to 125 microstrain (unconfined tests)
	85 to 115 microstrain (confined tests)
Load Standard Error	< 10%
Deformation Standard Error	< 10%
Deformation Uniformity	< 30%
Load Drift*	< 2%
Phase Angle Uniformity	$< 3^{o}$

* Included from NHI Course #131118 – Asphalt Mixture Performance Tester

4. Flow Number Testing

a) The flow number test shall be performed using the following testing parameters:
   a. 600 kPa (87 psi) deviator stress
   b. 0 kPa (0 psi) confining stress (i.e. Unconfined)
   c. 30 kPa (4.35 psi) contact stress
b) Ensure all four specimens are tested with the upper loading platen in the 'fixed' configuration.
   a. Do not utilize the ball in the upper platen for the IPC device.
   b. Do not utilize the rounded top plate for the Interlaken device.
c) 'Greased-Latex' friction reducers shall be used and prepared as per the instructions in AASHTO P 79-11. A new set (top and bottom) of friction reducers shall be used per specimen.
d) Specimens shall be temperature conditioned using the practices previously documented for testing dynamic modulus specimens.
e) The flow number samples shall be tested at the temperature of 51.5°C.
f) Temperature conditioning of flow number samples follows the same guidelines used for dynamic modulus samples (Section 3).
g) Continue the test until either of the following criteria is met…
   a. The on sample permanent deformation reaches 5 percent axial strain (50,000 microstrain)
   b. The sample runs for 10,000 cycles
      i. It is anticipated option "a" will occur with this particular mix.
h) The Francken model shall be used to determine the flow number.
   d. Both AMPT devices are equipped with testing software that allows the user to generate this.

i) Enter the required data into the provided data form for submission (the attached Excel file).

5. Data Reporting and Technical Support

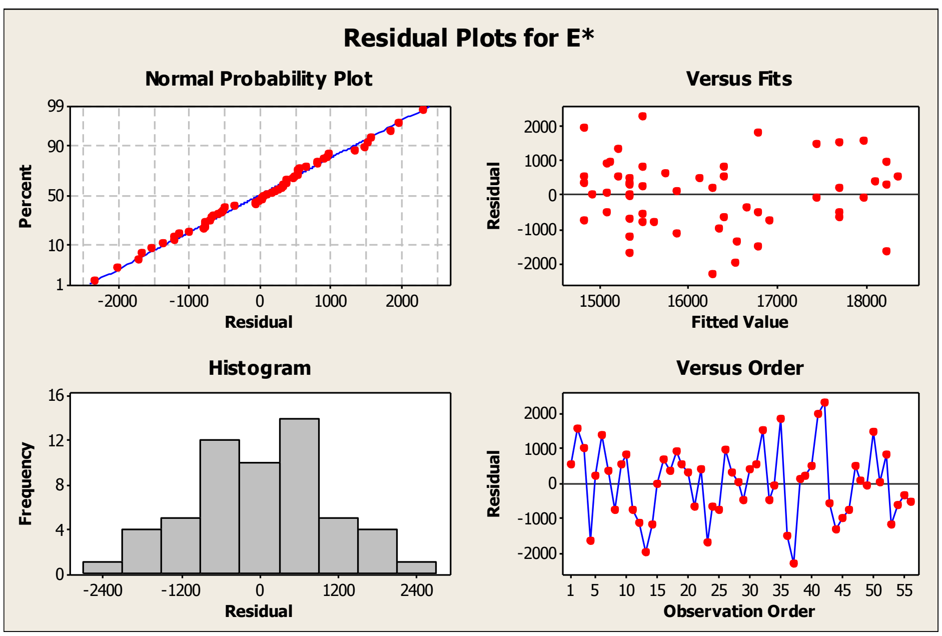
a) All Values shall be reported in SI Units
b) Please complete the EXCEL® data forms for both dynamic modulus and flow number tests and send them to Adam Taylor at tayloa3@auburn.edu.
c) If you have any questions about this testing, please contact Adam Taylor, P.E. at tayloa3@auburn.edu or 334-844-7337

APPENDIX C STATISTICAL ANALYSIS OF AIR VOID EFFECTS ON DYNAMIC MODULUS

Effect of Air Voids on E* at 4°C and 10 Hz

```
The regression equation is
E* = 25749 - 1318 Va

Predictor      Coef  SE Coef      T      P
Constant      25749     1209  21.29  0.000
Va          -1318.4    165.9  -7.95  0.000

S = 1037.27   R-Sq = 53.9%   R-Sq(adj) = 53.1%

Analysis of Variance

Source          DF         SS        MS      F      P
Regression       1   67986448  67986448  63.19  0.000
Residual Error  54   58100106   1075928
Total           55  126086554

Unusual Observations

Obs    Va     E*    Fit  SE Fit  Residual  St Resid
 37  7.20  13921  16256     139     -2335    -2.27R
 42  7.80  17780  15465     167      2315     2.26R

R denotes an observation with a large standardized residual.
```

Residual Plots for E*



Effect of Air Voids on E* at 4°C and 1 Hz

The regression equation is
E* = 21851 - 1271 Va

Predictor	Coef	SE Coef	T	P
Constant	21851	1083	20.17	0.000
Va	-1270.6	150.0	-8.47	0.000

S = 994.400   R-Sq = 54.0%   R-Sq(adj) = 53.3%

Analysis of Variance

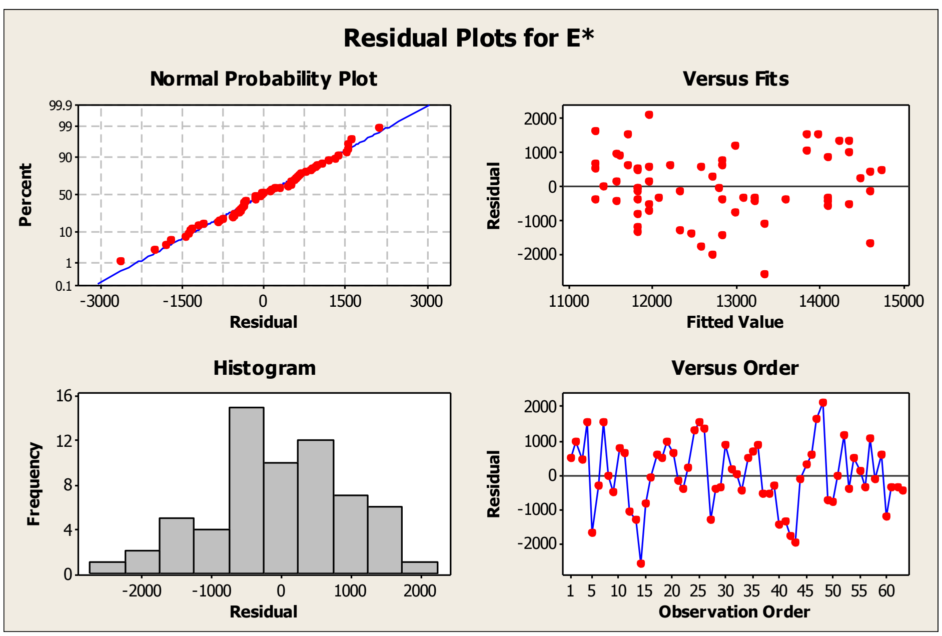
Source	DF	SS	MS	F	P
Regression	1	70950868	70950868	71.75	0.000
Residual Error	61	60318671	988831		
Total	62	131269539			

Unusual Observations

Obs	Va	E*	Fit	SE Fit	Residual	St Resid
14	6.70	10712	13338	144	-2626	-2.67R
43	7.20	10684	12703	125	-2019	-2.05R
48	7.80	14072	11941	157	2131	2.17R

R denotes an observation with a large standardized residual.

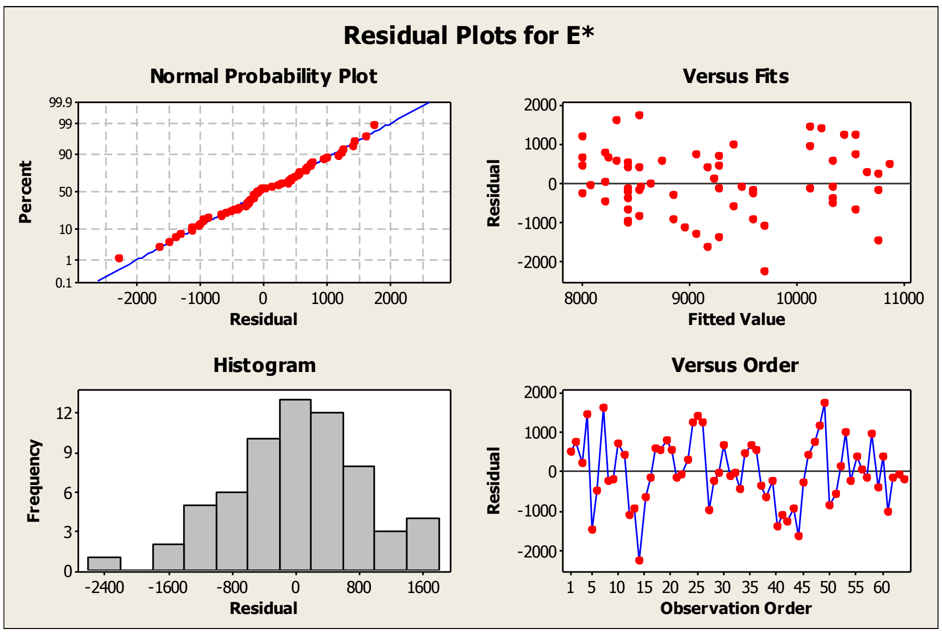
Residual Plots for E*



Effect of Air Voids on E* at 4°C and 0.1 Hz

```
The regression equation is
E* = 16791 - 1059 Va

Predictor      Coef  SE Coef      T      P
Constant    16790.9    921.6  18.22  0.000
Va          -1059.3    127.8  -8.29  0.000

S = 851.445   R-Sq = 52.6%   R-Sq(adj) = 51.8%

Analysis of Variance

Source          DF        SS        MS      F      P
Regression       1  49816715  49816715  68.72  0.000
Residual Error  62  44947485    724959
Total           63  94764200

Unusual Observations

Obs    Va     E*   Fit  SE Fit  Residual  St Resid
 14  6.70   7410  9693     122     -2283    -2.71R
 49  7.80  10275  8528     134      1747     2.08R

R denotes an observation with a large standardized residual.
```

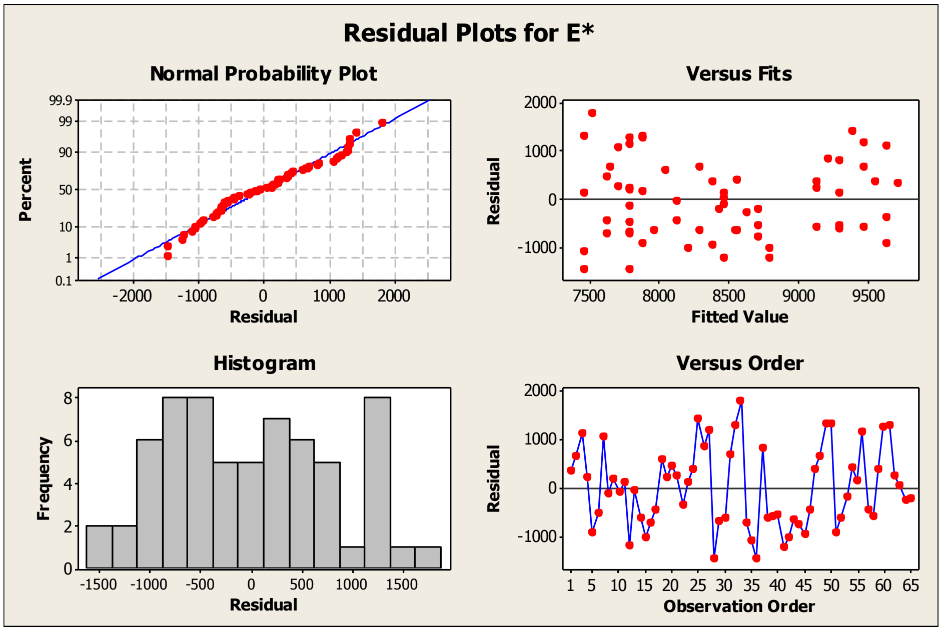
Residual Plots for E*



Effect of Air Voids on E* at 20°C and 10 Hz

```
The regression equation is
E* = 14417 - 840 Va

Predictor     Coef  SE Coef      T      P
Constant   14417.3    892.7  16.15  0.000
Va          -839.6    123.8  -6.78  0.000

S = 825.353   R-Sq = 42.2%   R-Sq(adj) = 41.3%

Analysis of Variance

Source          DF        SS        MS      F      P
Regression       1  31309018  31309018  45.96  0.000
Residual Error  63  42916045    681207
Total           64  74225063

Unusual Observations

Obs    Va    E*   Fit  SE Fit  Residual  St Resid
 33  8.23  9315  7508     167      1807     2.24R

R denotes an observation with a large standardized residual.
```

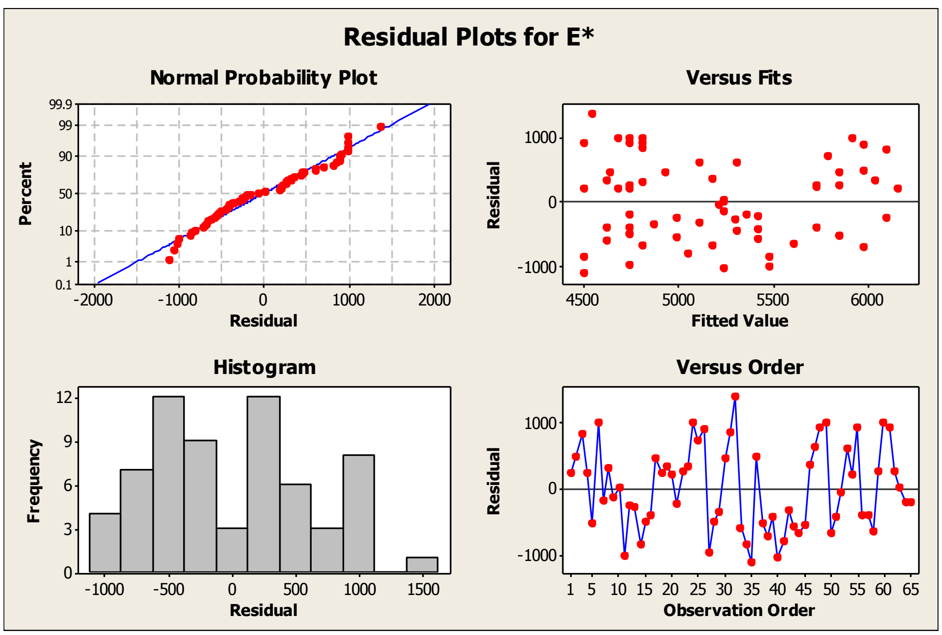
Residual Plots for E*



Effect of Air Voids on E* at 20°C and 1 Hz

```
The regression equation is
E* = 9625 - 618 Va

Predictor      Coef  SE Coef      T      P
Constant     9624.9    701.6  13.72  0.000
Va          -618.34    97.18  -6.36  0.000

S = 635.097   R-Sq = 39.1%   R-Sq(adj) = 38.2%

Analysis of Variance

Source          DF        SS        MS      F      P
Regression       1  16330373  16330373  40.49  0.000
Residual Error  63  25410925    403348
Total           64  41741297

Unusual Observations

Obs    Va      E*     Fit  SE Fit  Residual  St Resid
 32  8.23  5915.0  4536.0   129.4    1379.0     2.22R

R denotes an observation with a large standardized residual.
```

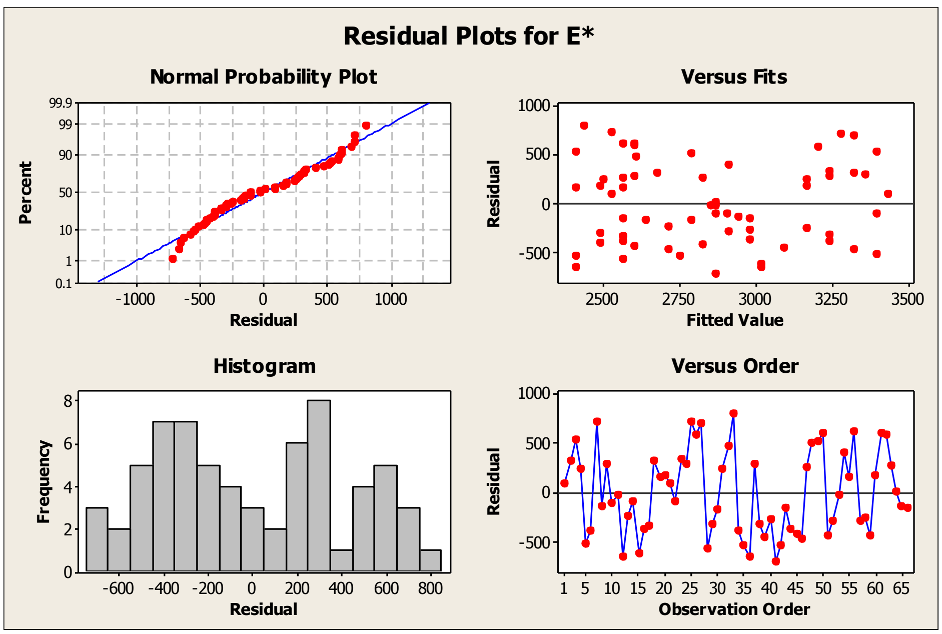
Residual Plots for E*



Effect of Air Voids on E* at 20°C and 0.1 Hz

```
The regression equation is
E* = 5555 - 379 Va

Predictor      Coef   SE Coef      T      P
Constant     5555.5     456.4  12.17  0.000
Va          -378.83     63.41  -5.97  0.000

S = 424.637   R-Sq = 35.8%   R-Sq(adj) = 34.8%

Analysis of Variance

Source          DF        SS       MS      F      P
Regression       1   6436673  6436673  35.70  0.000
Residual Error  64  11540258   180317
Total           65  17976931
```

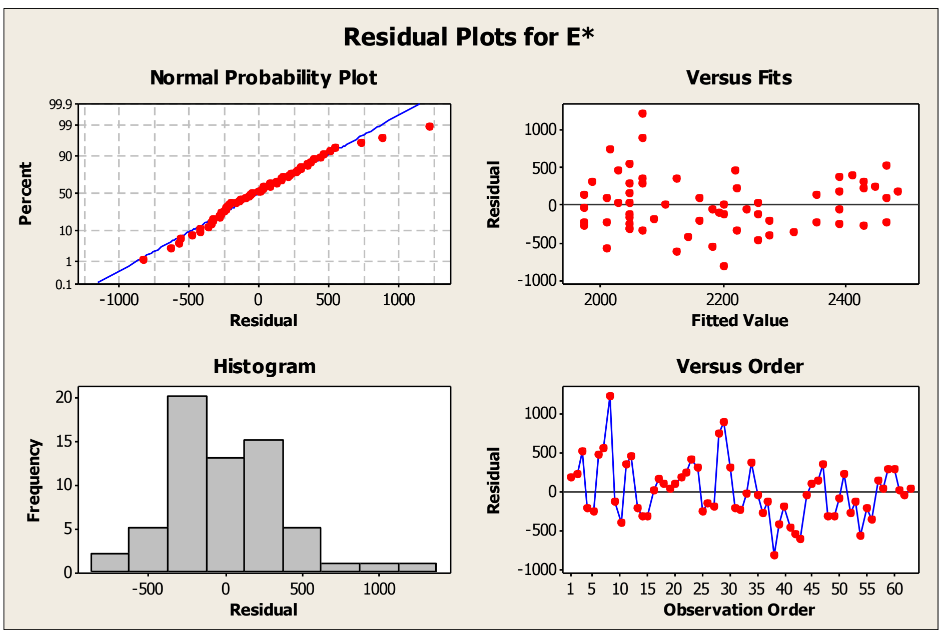
Residual Plots for E*



Effect of Air Voids on E* at 40°C and 10 Hz

```
The regression equation is
E* = 3560 - 192 Va

Predictor      Coef  SE Coef      T      P
Constant     3560.3    413.7   8.61  0.000
Va          -191.55    57.24  -3.35  0.001

S = 376.048   R-Sq = 15.5%   R-Sq(adj) = 14.1%

Analysis of Variance

Source          DF        SS       MS      F      P
Regression       1   1583638  1583638  11.20  0.001
Residual Error  61   8626132   141412
Total           62  10209770

Unusual Observations

Obs    Va      E*     Fit  SE Fit  Residual  St Resid
  8  7.80  3289.0  2066.3    59.2    1222.7     3.29R
 29  7.79  2958.0  2068.2    58.8     889.8     2.40R
 38  7.10  1369.0  2200.4    47.6    -831.4    -2.23R

R denotes an observation with a large standardized residual.
```

Residual Plots for E*



Effect of Air Voids on E* at 40°C and 1 Hz

The regression equation is
E* = 1700 - 99.0 Va

Predictor	Coef	SE Coef	T	P
Constant	1700.0	222.3	7.65	0.000
Va	-98.97	30.85	-3.21	0.002

S = 206.105   R-Sq = 14.2%   R-Sq(adj) = 12.9%

Analysis of Variance

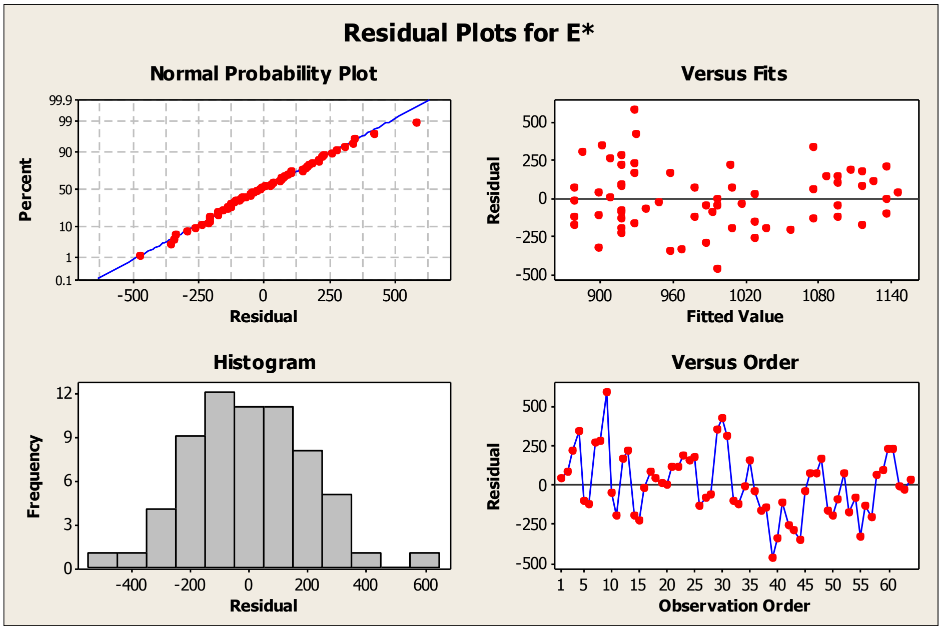
Source	DF	SS	MS	F	P
Regression	1	437274	437274	10.29	0.002
Residual Error	62	2633704	42479		
Total	63	3070978			

Unusual Observations

Obs	Va	E*	Fit	SE Fit	Residual	St Resid
9	7.80	1514.0	928.0	32.5	586.0	2.88R
30	7.79	1350.9	929.0	32.3	421.9	2.07R
39	7.10	527.1	997.3	25.8	-470.2	-2.30R

R denotes an observation with a large standardized residual.

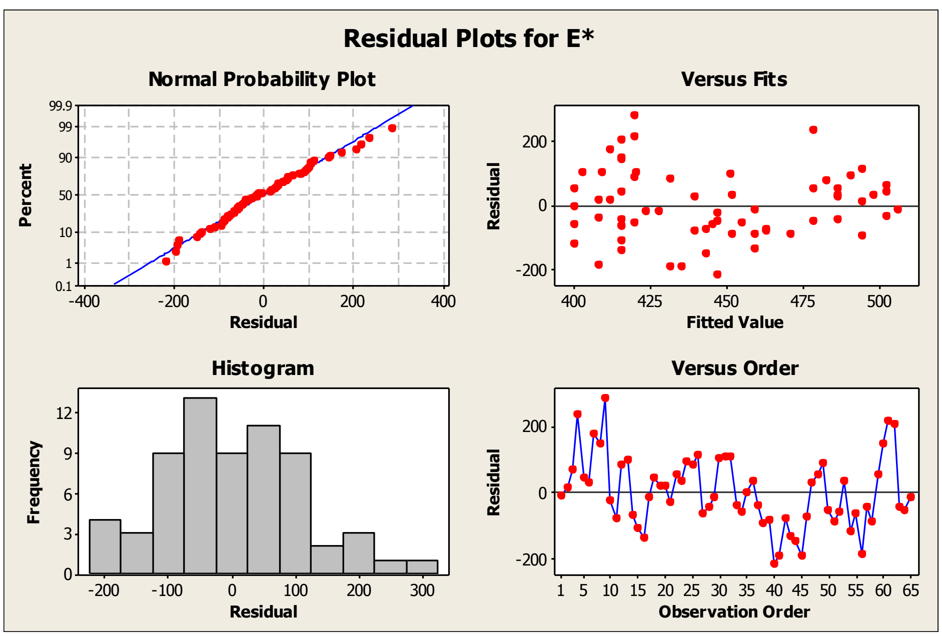
Residual Plots for E*



Effect of Air Voids on E* at 40°C and 0.1 Hz

```
The regression equation is
E* = 726 - 39.3 Va

Predictor      Coef  SE Coef      T      P
Constant      726.2    117.0   6.21  0.000
Va           -39.30    16.25  -2.42  0.018


S = 108.832   R-Sq = 8.5%   R-Sq(adj) = 7.0%

Analysis of Variance

Source          DF      SS     MS     F      P
Regression       1   69284  69284  5.85  0.018
Residual Error  63  746197  11844
Total           64  815481

Unusual Observations

Obs    Va     E*    Fit  SE Fit  Residual  St Resid
  4  6.30  715.8  478.6    19.3     237.2     2.21R
  9  7.80  704.8  419.7    17.1     285.1     2.65R
 40  7.10  228.8  447.2    13.5    -218.4    -2.02R
 61  7.80  638.2  419.7    17.1     218.6     2.03R

R denotes an observation with a large standardized residual.
```

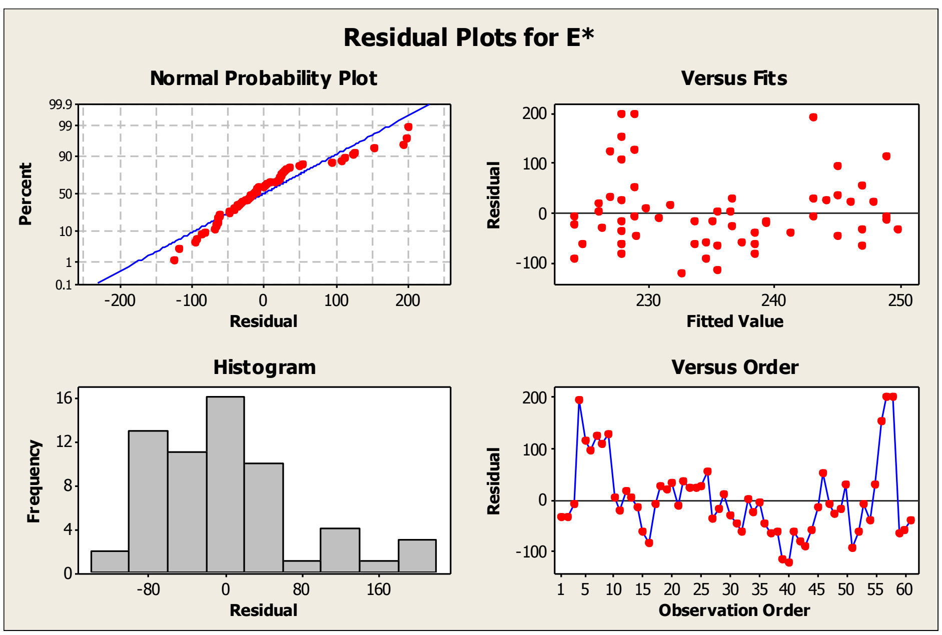
Residual Plots for E*



Effect of Air Voids on E* at 40°C and 0.01 Hz

```
The regression equation is
E* = 303 - 9.6 Va

Predictor     Coef  SE Coef      T      P
Constant    303.46    83.71   3.63  0.001
Va           -9.57    11.66  -0.82  0.415

S = 75.0199   R-Sq = 1.1%   R-Sq(adj) = 0.0%

Analysis of Variance

Source          DF      SS    MS     F      P
Regression       1    3790  3790  0.67  0.415
Residual Error  59  332051  5628
Total           60  335841

Unusual Observations

Obs    Va      E*     Fit  SE Fit  Residual  St Resid
  4  6.30  437.47  243.16   13.63    194.31     2.63R
 56  7.90  381.16  227.85   13.16    153.31     2.08R
 57  7.80  428.84  228.81   12.39    200.04     2.70R
 58  7.90  427.02  227.85   13.16    199.17     2.70R

R denotes an observation with a large standardized residual.
```

Residual Plots for E*



APPENDIX D STATISTICAL ANALYSIS OF AIR VOID EFFECTS ON FLOW NUMBER

Effect of Air Voids on Fn

The regression equation is
Fn = 898 - 95.3 Va

Predictor	Coef	SE Coef	T	P
Constant	898.01	48.45	18.54	0.000
Va	-95.268	6.749	-14.12	0.000

S = 52.9232   R-Sq = 70.1%   R-Sq(adj) = 69.7%

Analysis of Variance

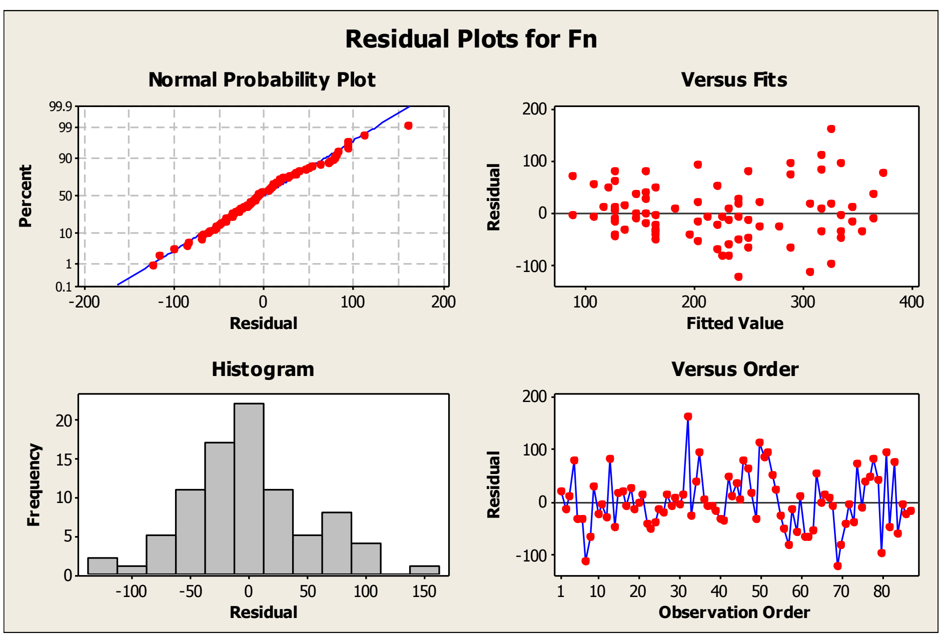
Source	DF	SS	MS	F	P
Regression	1	558163	558163	199.28	0.000
Residual Error	85	238073	2801		
Total	86	796237			

Unusual Observations

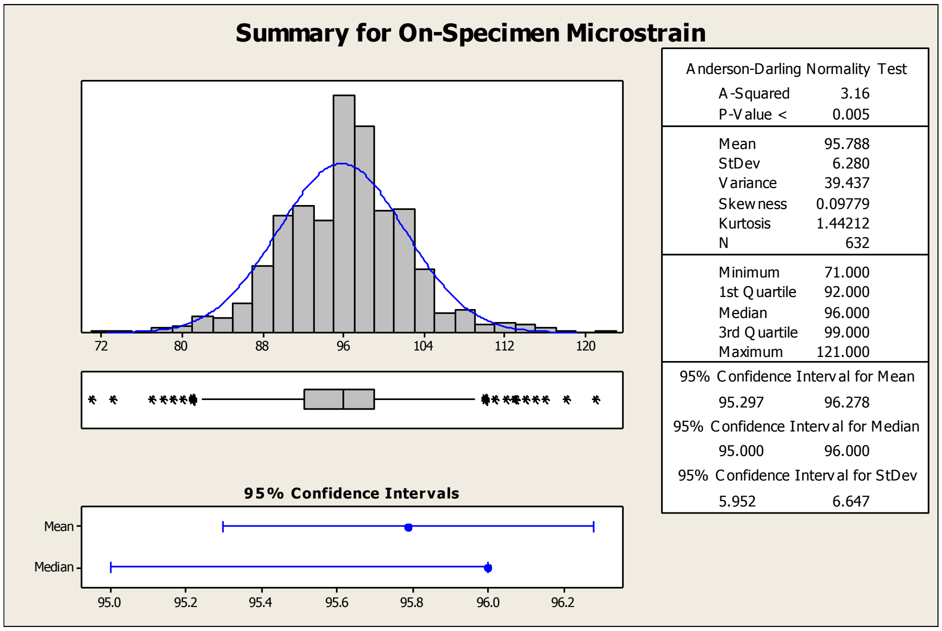
Obs	Va	Fn	Fit	SE Fit	Residual	St Resid
7	6.20	192.00	307.35	8.46	-115.35	-2.21R
32	6.00	487.00	326.40	9.50	160.60	3.08R
50	6.10	429.00	316.87	8.97	112.13	2.15R
69	6.90	118.00	240.66	5.88	-122.66	-2.33R

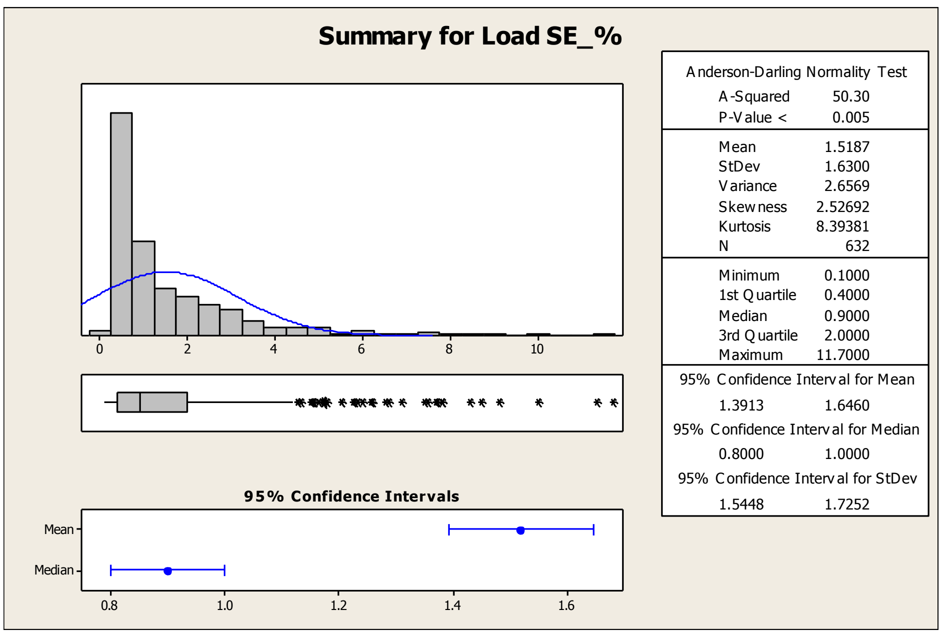
R denotes an observation with a large standardized residual.

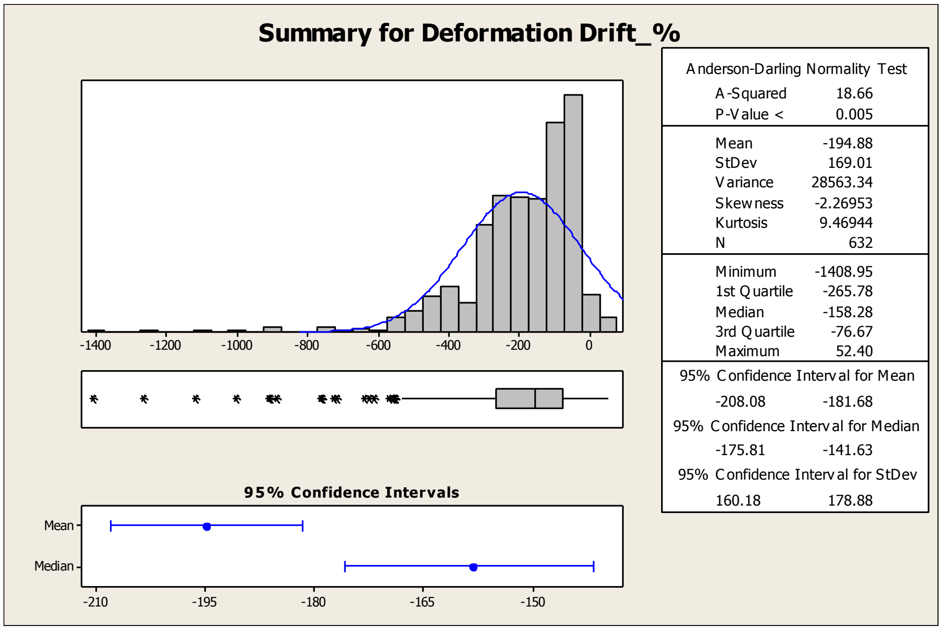
Residual Plots for E*

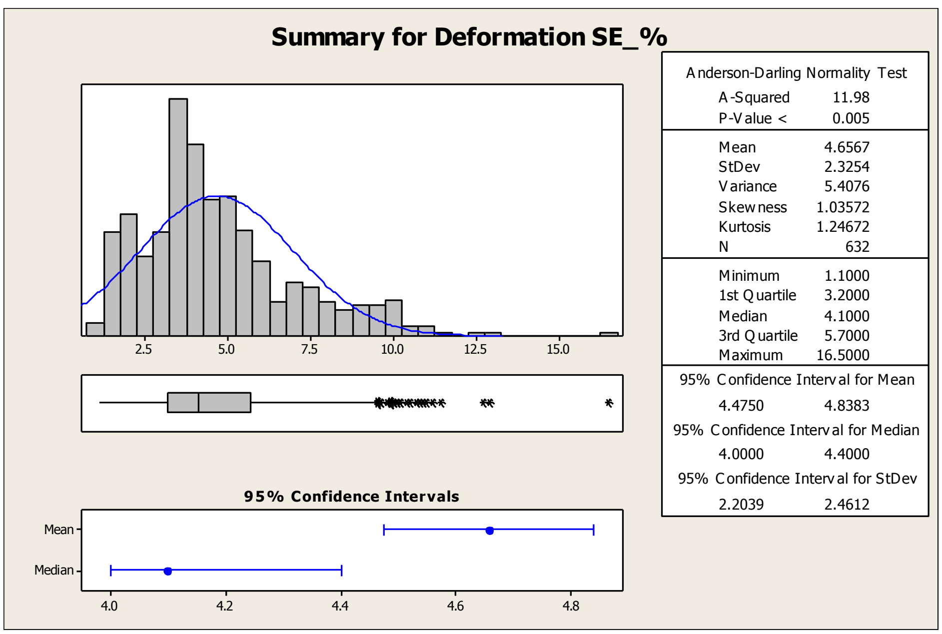


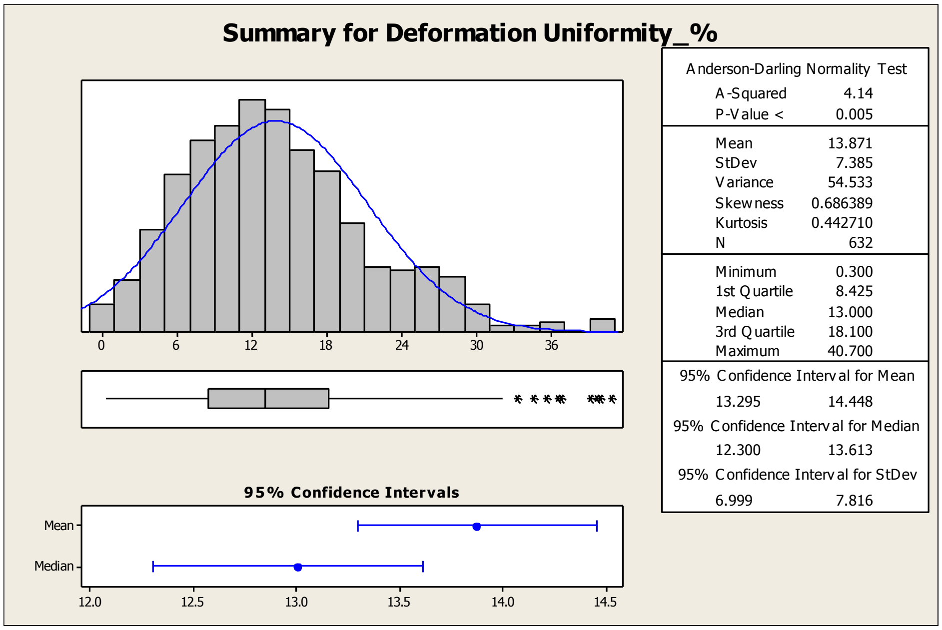
APPENDIX E STATISTICS SUMMARY OF DYNAMIC MODULUS DATA QUALITY INDICATORS

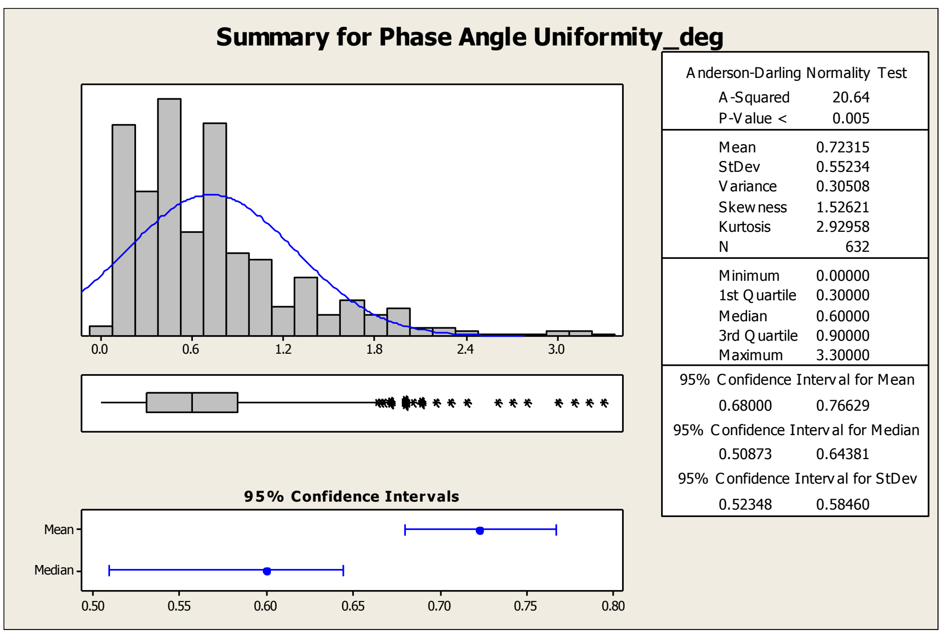





Summary for Deformation Drift_%
Anderson-Darling Normality Test
A-Squared 18.66
P-Value < 0.005
Mean -194.88
StDev 169.01
Variance 28563.34
Skewness -2.26953
Kurtosis 9.46944
N 632
Minimum -1408.95
1st Quartile -265.78
Median -158.28
3rd Quartile -76.67
Maximum 52.40
95% Confidence Interval for Mean
-208.08 -181.68
95% Confidence Interval for Median
-175.81 -141.63
95% Confidence Interval for StDev
160.18 178.88
-1400 -1200 -1000 -800 -600 -400 -200 0
95% Confidence Intervals
Mean
Median
-210 -195 -180 -165 -150


Summary for Deformation SE_%
Anderson-Darling Normality Test
A-Squared 11.98
P-Value < 0.005
Mean 4.6567
StDev 2.3254
Variance 5.4076
Skewness 1.03572
Kurtosis 1.24672
N 632
Minimum 1.1000
1st Quartile 3.2000
Median 4.1000
3rd Quartile 5.7000
Maximum 16.5000
95% Confidence Interval for Mean
4.4750 4.8383
95% Confidence Interval for Median
4.0000 4.4000
95% Confidence Interval for StDev
2.2039 2.4612
2.5 5.0 7.5 10.0 12.5 15.0
95% Confidence Intervals
Mean
Median
4.0 4.2 4.4 4.6 4.8


Summary for Deformation Uniformity_%
Anderson-Darling Normality Test
A-Squared 4.14
P-Value < 0.005
Mean 13.871
StDev 7.385
Variance 54.533
Skewness 0.686389
Kurtosis 0.442710
N 632
Minimum 0.300
1st Quartile 8.425
Median 13.000
3rd Quartile 18.100
Maximum 40.700
95% Confidence Interval for Mean
13.295 14.448
95% Confidence Interval for Median
12.300 13.613
95% Confidence Interval for StDev
6.999 7.816
0 6 12 18 24 30 36
95% Confidence Intervals
Mean
Median
12.0 12.5 13.0 13.5 14.0 14.5


Summary for Phase Angle Uniformity_deg
Anderson-Darling Normality Test
A-Squared 20.64
P-Value < 0.005
Mean 0.72315
StDev 0.55234
Variance 0.30508
Skewness 1.52621
Kurtosis 2.92958
N 632
Minimum 0.00000
1st Quartile 0.30000
Median 0.60000
3rd Quartile 0.90000
Maximum 3.30000
95% Confidence Interval for Mean
0.68000 0.76629
95% Confidence Interval for Median
0.50873 0.64381
95% Confidence Interval for StDev
0.52348 0.58460
0.0 0.6 1.2 1.8 2.4 3.0
95% Confidence Intervals
Mean
Median
0.50 0.55 0.60 0.65 0.70 0.75 0.80