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BALANCED ASPHALT CONCRETE MIX PERFORMANCE IN UTAH

PHASE VI: MULTI-LABORATORY TESTING OF IDEAL-CT

Prepared For:

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RESEARCH
UDOT
Keeping Utah Moving
Utah Department of Transportation - Research Division
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16. Abstract

This report describes the research efforts aimed at determining the repeatability of the IDEAL-CT test for asphalt concrete mixtures. It follows a series of studies investigating different cracking tests. Three mixes in common production in the northern part of Utah were investigated by three different labs experienced in performance testing. Within-lab and between-lab variability were studied as well as a number of factors likely to cause variability. Recommendations were developed for specimen preparation, minimum number of replicates, and how to discard outliers. It was found that the test could be repeated within laboratory within a coefficient of variation, CV, of 15% and between laboratories within a CV value of 20% using properly trimmed results. Four replicates are recommended with the result farthest from the mean discarded. No correlation between higher CT Index and greater durability was identified in this series of studies.

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UNIT CONVERSION FACTORS

Units used in this report and not conforming to the UDOT standard unit of measurement (U.S. Customary system) are given below with their U.S. Customary equivalents:

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

*SI is the symbol for the International System of Units. (Adapted from FHWA report template, Revised March 2003)

LIST OF ACRONYMS AND ABBREVIATIONS

AASHTO – American Association of State Highway and Transportation Officials

ASTM – American Society of Testing and Materials

BBR – Bending Beam Rheometer, refers to AASHTO TP-125

CT Index – Cracking Tolerance Index

DCT – Disc-Shaped Compact Tension Test

Department – Utah Department of Transportation

FI – Flexibility Index

HWT – Hamburg Wheel Tracking Test

IDEAL-CT - Indirect Tension Asphalt Cracking Test, refers to ASTM D8225

IFIT – Illinois Flexibility Index Test, refers to AASHTO TP-124

NMAS – Nominal Maximum Aggregate Size

Ndes – Design number of gyrations

RAP – Recycled Asphalt Pavement

SCB – Semi-Circular Bending

UDOT – Utah Department of Transportation

U of U – University of Utah

VMA – Voids in Mineral Aggregate

EXECUTIVE SUMMARY

This report describes the research efforts aimed at determining the repeatability of the IDEAL-CT test for asphalt concrete mixtures. It follows a series of studies investigating different cracking tests. Three mixes in common production in the northern part of Utah were investigated by three different labs experienced in performance testing.

The within-lab and between-lab variability were studied as well as a number of factors likely to cause variability. It was found that the test could be repeated within laboratory within a coefficient of variation, CV, of 15% and between laboratories within a CV value of 20% using properly trimmed results. Preparation and testing of four replicate samples is recommended with the result farthest from the mean discarded if the variability exceeds 15%.

Regarding the test procedures, it was found that if the number of gyrations exceeded the Ndes of the mixtures, some aggregates could be broken and the variability could increase. In those cases, preparation of thicker samples is recommended. This is possible since specimen thickness is already considered as part of the calculation of the cracking tolerance index.

Finally, it was found that the IDEAL-CT test meets many requirements for a quality control test; however, no correlation between higher CT Index and greater durability was identified in this series of studies.

1.0 INTRODUCTION

1.1 Problem Statement

The Utah Department of Transportation (UDOT) instituted its first performance-based test into specification in the early 2000s when the Hamburg Wheel Tracking (HWT) Device was required for asphalt mix design verification. Although this action solved a rutting issue in the State's pavement system, it tended to favor harder mixes leading to cracking issues. It is the opinion of UDOT materials engineers that the adoption of the SuperPave system alone, notwithstanding HWT effects, caused mixes to be overly dry and raveling-prone. It was surmised that increasing binder content and binder modification would reduce raveling and cracking tendencies, so a number of specification modifications were undertaken. Some improvement resulted from increasing VMA, reducing maximum nominal aggregate size, reducing voids at Ndes, and limiting recycled material. These goals needed to be balanced against rutting for a good performing mix. Since specification modification continued to produce spotty results and because a number of cracking tests were being developed, UDOT undertook a selection process to find an appropriate test that could discriminate between mixes that crack and mixes that don't. The following criteria were desired to be met:

- The test must have meaning. It must be able to rank mixes in order from less cracking to more cracking-susceptible.
- The test must be rapid. It must produce results within 24 hours of sampling.
- The test must be precise. Tests with high variation cannot be used for specification. A low number of samples and a low number of replicates must be required.
- The test must be repeatable between labs. QC and QA must be equivalent, or processes cannot be controlled.
- The test must be simple. It must lend itself to field lab conditions. Sample fabrication must involve the least amount of manipulation. Conditioning must not require sophisticated procedures. Existing training and equipment must be exploited. Analysis must not be complex.
- The test must be inexpensive. A $50,000 setup limit is desired.

It must be noted here that most of the cracking tests being developed assume a non-uniform material in which a crack is always present (Fujie Zhou, et al., 2022), and the tests focus on the crack propagation properties of the mix. However, this interpretation may or may not always be valid given that some of the tests demonstrate a crack initiation energy and therefore some resistance to crack development. In some mixtures, crack resistance may prove to be as important as resistance to crack propagation.

This is the sixth in a series of investigations of test procedures as UDOT attempts to find a method that meets all of the listed requirements. UDOT has rejected tests such as SCB Jc, DCT, IFIT and others due to complexity, timeliness, cost and sample preparation issues. The most promising candidate to date is the IDEAL-CT test developed at the Texas Transportation Institute. A ruggedness study published in 2022 makes some recommendations for modifications to ASTM D8225-19 which should be considered going forward.

Development and adoption of a laboratory test that can evaluate asphalt mixtures for intermediate-temperature properties has been an important goal of UDOT during the last few years. The high-temperature properties of asphalt mixtures are being addressed with the HWT Device. The low-temperature properties are being addressed with the Bending Beam Rheometer (BBR) test on asphalt mixtures. After some testing and evaluation, the IDEAL-CT test (ASTM D8225) was identified as a promising test to determine intermediate-temperature properties. Once the tests for both temperature extremes as well as intermediate-temperature properties of asphalt mixtures have been adopted, development of a performance-based specification will be possible resulting in mix designs that can be tailored to the harsh environment seen in Utah. The result can be a balanced, performance-based mixture optimized on all distresses. This concept is what is referred to as balanced mix design.

Adoption of an intermediate-temperature cracking test is the final component of the performance-related specifications being adopted by UDOT. However, as part of adopting the test, it is necessary to understand the within- and between-laboratory variability of the test. Even though the IDEAL-CT test is becoming popular with state agencies, including UDOT, there is no information regarding the variability and reproducibility of the test; therefore, before the test is adopted, it is necessary to understand its variability. Furthermore, some asphalt mix producers are starting to use the test for mix design; thus it is important that a proper variability study be conducted.

1.2 Objectives

The objectives of this research are:

- Develop within- and between-laboratory variability statements for the IDEAL-CT test in support of its adoption as a specification for intermediate-temperature testing.
- Recommend a preferred sample height.
- Recommend number of replicate samples and analysis to achieve a reasonable variability.

1.3 Scope

As part of this work, testing of three plant-produced, 'standard' asphalt mixtures was performed at three labs following the procedures outlined in ASTM D8225: *Standard Test Method for Determination of Cracking Tolerance Index of Asphalt Mixture Using the Indirect Tensile Cracking Test at Intermediate Temperature*. All three labs have significant experience in testing and evaluation of asphalt mixtures using this test, and all of them used equipment manufactured by the same supplier. The variables for this research are shown in Table 1-1.

Table 1-1 Variables Used in This Study

Variable	Number	Comments
Testing laboratories	3	UDOT Central, U of U, PEPG
Asphalt mixtures	3	Plant produced (provided by Staker, Kilgore, and Geneva)
Aggregate size	1	12.5-mm nominal maximum size
Binder grade	1	All mixtures used PG 64-34 from different suppliers
Sample thickness	2	62-mm and 75-mm
Target air voids	1	7 ± 0.5 % - Values outside target were still included
Loading head speed	1	50 mm/min, displacement controlled
Test temperature	1	25 ºC
Samples per condition	9	

1.4 Outline of Report

This report contains the following chapters:

- Introduction

  Provides a brief introduction of the research and describes the problem statement and the scope of the work.
- Research Methods

  Describes sample preparation and testing protocols.
- Data Analysis

  Discusses factors that affect the variability in the results, including number of gyrations, specimen height, and air voids. Describes how and why certain data was excluded from the analysis.
- Laboratory Evaluation

  Compares the results across different participant labs and analyzes the within-lab variability as well as the between-lab differences.
- Conclusions and Recommendations

  Summarizes the conclusions and provides recommendations regarding the determination of the CT Index for asphalt mixtures.

2.0 RESEARCH METHODS

2.1 Overview

Evaluating the variability of the IDEAL-CT tests was done using three different laboratories with extensive testing experience. Hot-mix asphalt was collected from three different plants and distributed among the different labs. Each lab proceeded to test the samples in a consistent manner. The results from each lab were compared with the purpose of evaluating the variability of the testing procedure and not the expected performance of the mix itself. Since the performance of the mix is not being considered, the source of the mix is given as an identifier only; mix properties are not relevant and are not included in this report.

2.2 Sample Preparation

Hot-mix asphalt was delivered in metal buckets to each of the participant laboratories. While it is known that slight differences between materials can exist due to segregation and sampling error, it was assumed that all of the buckets contained material with identical composition.

When the labs were ready for testing, the buckets were heated overnight to a temperature of 120 ºC while keeping the lid on to prevent further aging. Once the mix was pliable, the material for each sample replicate was separated by quartering or using a riffle splitter, as appropriate. The hot-mix was weighed based on the given maximum specific gravity (Gmm) so that specimens could be compacted to the target air voids at the two specified heights. The mix was heated to the appropriate compacting temperature and compacted to height using the Superpave Gyratory Compactor (SGC) following the procedures described in AASHTO T312: *Standard Method of Test for Preparing and Determining the Density of Asphalt Mixtures by Means of the Superpave Gyratory Compactor*. Once compacted, the air voids value of each sample was determined following the procedures described in AASHTO T269: *Percent Air Voids in Compacted Dense and Open Asphalt Mixtures*. The number of gyrations to reach compaction and the air voids for each sample were recorded. Samples whose air voids fell outside the specified range of 7 ± 0.5 percent were still tested.

2.3 IDEAL-CT Testing

Testing was done based on ASTM D8225: *Standard Test Method for Determination of Cracking Tolerance Index of Asphalt Mixture Using the Indirect Tensile Cracking Test at Intermediate Temperature*. To ensure consistency, the samples were tested within 8 to 20 hours after compaction.

All three laboratories used the same brand of servo-hydraulic equipment; thus the effects of equipment type (i.e., servo-hydraulic vs. electromechanics) are not evaluated as part of this study. To ensure proper temperature during testing, a “dummy sample” fitted with a calibrated thermocouple would accompany the sample during conditioning and then testing. The speed of the loading head was constant at 50 mm/min. A picture of the testing equipment at the University of Utah is shown in Figure 2-1.

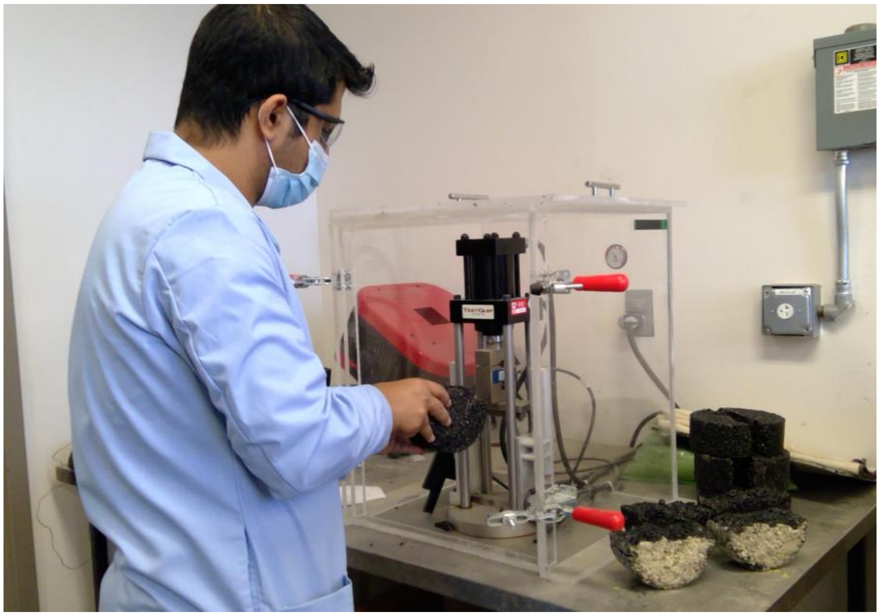

Figure 2-1 IDEAL-CT Testing at the University of Utah

2.4 Data Analysis

The testing equipment digitally collected load-displacement data and calculated the cracking tolerance (CT) index for each sample. This process resulted in 18 values per lab for each mix (9 reps x 2 heights) for a total of 162 values. The CT Index was collected and analyzed using different statistical techniques as described in Chapter 3.

2.5 Summary

This chapter describes how asphalt mix was collected from three different plants and distributed to the three different labs. Standard protocols were used to handle the material as well as the sample compaction. Samples were compacted to target air voids of 7 ± 0.5 % and heights of 62 mm and 75 mm. Testing was done within 20 hours of compaction, and all three laboratories used the same brand of servo-hydraulic equipment. The CT Index of each sample was determined and used for analysis.

3.0 DATA ANALYSIS

3.1 Overview

This chapter presents the data obtained from the IDEAL-CT tests on three different mixtures as reported by the three participant laboratories.

3.2 Data Collected

A total of 167 values were collected for this study. A summary of the data is shown in Table 3-1 with the complete set of data shown in Appendix A. It should be noted that the labels on the mixtures are used as identifiers only; the results are not meant to compare the mixtures to each other since they were not designed based on their CT Index. However, the data shows that the mixtures selected are different in terms of their CT Index and thus their potential performance.

Table 3-1 Summary of Data Collected

	All Data	Staker	Geneva	Kilgore
Mean	124.1	91.9	106.5	178.7
Standard Error	3.831	2.967	4.177	5.681
Median	112.6	88.0	102.6	177.2
Mode	106.1	87.5	102.1	158.3
Standard Deviation	49.512	23.172	30.407	41.355
As % of mean	--	25.2	28.5	23.1
Sample Variance	2451.42	536.92	924.60	1710.21
Kurtosis	0.3974	-0.3081	0.2456	0.1804
Skewness	0.9019	0.2652	0.6510	0.4546
Range	235.5	106.7	129.0	182.1
Minimum	43.5	43.5	55.4	96.9
Maximum	279.0	150.2	184.4	279.0
Sum	20722.8	5604.3	5647.1	9471.4
Count	167	61	53	53
Average Gyrations*	--	55	122	50

* this is the average number of gyrations required to compact all samples by all labs

3.2.1 Variance

Table 3-1 shows that the variances (standard deviation) of the results are not the same for each mix (heteroscedasticity). To determine if the difference in variance is statistically significant, an F-test for equal variance was performed between the largest and the smallest variance. The results, shown in Table 3-2, indicate that the hypothesis that variances for these two mixtures are the same is rejected, or in other words, we conclude that the two variances are different. While it is possible that, if the variances for all three mixtures were analyzed together using a Bartlett's test, the conclusion might be different, the reality is that the mixtures are not meant to be compared to each other. Based on these results, each mix will be treated separately in this report.

Table 3-2 F-Test for Equal Variance

	Kilgore	*Staker*	*Conclusion*
Mean	178.7	91.9	
Variance	1710.21	536.92	
Observations	53	61	
df	52	60	
F	3.1852		
P(F≤f) one-tail	1.0492E-05		$p < 0.05$ reject
F Critical one-tail	1.5534		

Table 3-1 also shows that the variance increases as the mean increases. When the square root of the variance (i.e., the standard deviation) is expressed as a percent of the mean, the values range from 23 to 28 percent. This gives an indication that the coefficient of variation of the population is around 25% before any outlying observations are evaluated and possibly eliminated. The implications of this value will be discussed in Chapter 4.

3.2.2 Normality of Data

Table 3-1 shows that there is some positive skewness in the data. High levels of skewness indicate the data is not normally distributed, a situation generally not desirable since it can undermine some statistical analysis. While there are no official criteria about cut-off values to decide how large the skew must be to indicate non-normality of the data, values between -2 to +2 are considered as acceptable (George and Malley, 2010). As seen in the table, all values are less than 1; thus it is reasonable to consider the data as normally distributed.

An additional method to determine the normality of the data is to graphically plot the data on a quantile-quantile (Q-Q) plot which shows the distribution of the data against the expected normal distribution. For normally distributed data, observations should lie approximately on a straight line. Possible outliers are points at the ends of the line, distant from the bulk of the observations. This is shown in Figure 3-1.

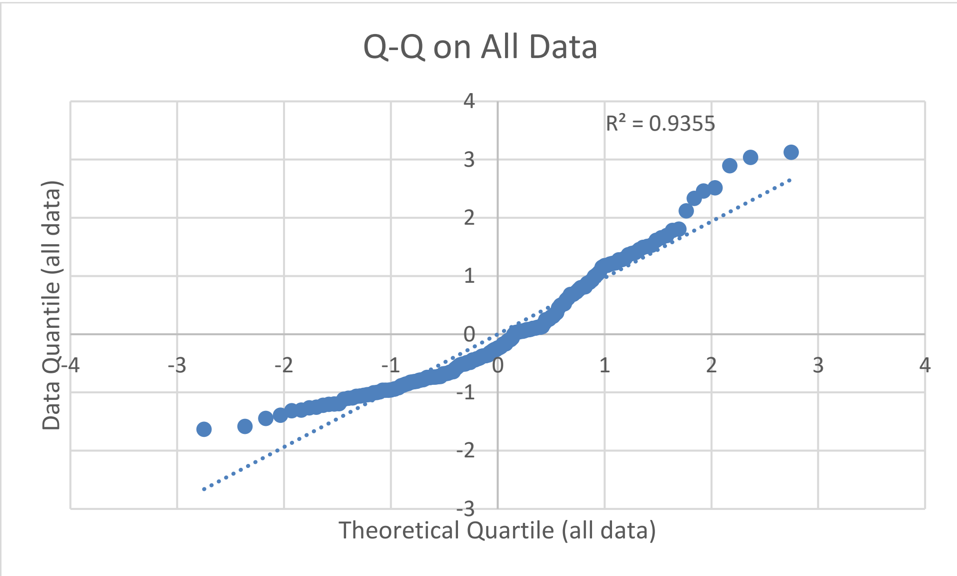

Figure 3-1 Q-Q Plot of All Data

Figure 3-1 shows that the data could be considered normally distributed even though there are some deviations from a straight line. The deviations are likely caused by outliers that require further investigation. While it is impossible to know the cause of all outliers, some of them are suspected to derive from a difference in material composition, either from inherent inhomogeneities or from issues during the compaction process.

3.3 Number of Gyrations

An important parameter that was recorded during compaction was the number of gyrations. Even though all mixtures were designed for 75 gyrations, one of the mixtures seemed to require, on average, a high number of gyrations in relation to the other mixtures to reach the desired height of the specimen (122 vs. ~50 gyrations). It was hypothesized that, once the number of gyrations reached values above Ndes (75 gyrations for these mixtures), aggregates are broken, resulting in uncoated surfaces within the mix, affecting the CT Index, and increasing the variability of the results. To verify this hypothesis, the data for each mixture was separated into those values that required more than 75 gyrations and those that did not. A Student's t-test assuming unequal variance was performed for each mix with the results shown in Table 3-3.

Table 3-3 Analysis of Number of Gyrations

		Gyrations > 75	***Gyrations < 75***	**Conclusion**
Staker	Mean	74.8	94.8	
	Variance	771.26	450.66	
	Observations	9	52	
	t-Stat	-2.0565		
	t-critical (2-tail)	2.2281		
	p(T≤t) two tail	0.0667		p > 0.05 fail to reject
Geneva	Mean	99.8	122.3	
	Variance	800.08	907.52	
	Observations	37	16	
	t-Stat	-2.5440		
	t-critical (2-tail)	2.0518		
	p(T≤t) two tail	0.0170		p < 0.05 reject
Kilgore	Mean	159.5	181.2	
	Variance	828.03	1789.21	
	Observations	6	47	
	t-Stat	-1.6293		
	t-critical (2-tail)	2.3060		
	p(T≤t) two tail	0.1419		p > 0.05 fail to reject

The data in Table 3-3 shows that, regardless of the mixture analyzed, those samples that required more than 75 gyrations have a lower CT Index. In other words, too many gyrations decrease the CT Index. The Student's t-test indicates that for those mixtures that, on average, required less than 75 gyrations to compact, the hypothesis that the means are equal is not rejected, meaning that there is no statistical difference in their average CT Index; however, for the mix that, on average, required 122 gyrations, the hypothesis that the means are equal is rejected. The variance of the results, which is an indicator of the variability, does not show a consistent trend with number of gyrations. In two cases it increased, and it decreased in one.

The data presented in Table 3-3 indicates that data from samples compacted using a high number of gyrations can result in different CT Index values. As was previously mentioned, these different values can be considered outliers and not representative of the actual mixture properties. To further verify this hypothesis, the data from samples compacted to more than 75 gyrations was excluded from the analysis, and a new Q-Q plot was generated. This is shown in Figure 3-2.

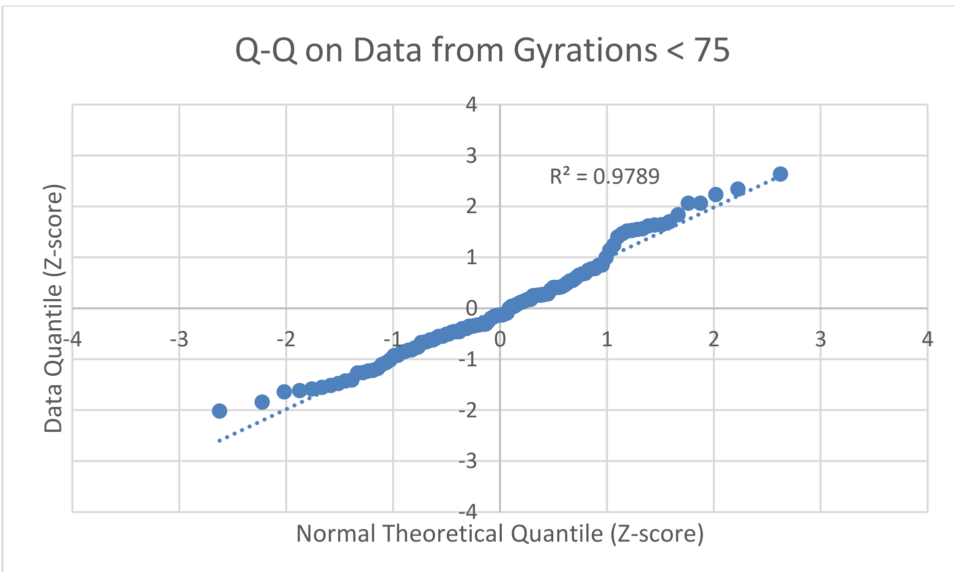

Figure 3-2 Q-Q Plot of Data from Samples Compacted Using Less Than 75 Gyrations

Comparing Figure 3-1 and 3-2 it is evident that, once the data from samples compacted to more than 75 gyrations is removed, the data more closely follows a straight line in the Q-Q plot. In other words, when samples can be compacted using less than 75 gyrations, the resulting CT Index values more closely follow a normal distribution. The implications of these results on routine testing will be discussed in Chapter 4; however, based on these observations, it was decided that further data analysis would be done only on specimens that required less than 75 gyrations to compact.

The data shown in Table 3-3 and Figure 3-2 combines samples compacted to heights of 62 mm and 75 mm. It can be argued that the taller samples allow for better aggregate distribution during compaction thus resulting in a lower number of gyrations (and a more representative value). Further analysis of the data shows that to be the case; for two of the mixtures, the only samples that required more than 75 gyrations were compacted to a height of 62 mm. In other words, samples with a height of 75 mm are easier to compact. For the mix that, on average, required a larger number of gyrations, the majority (22 out of 37) of the 62-mm samples required more than 75 gyrations. This indicates that, in some cases, a height of 75 mm might be preferred and might result in more representative samples.

3.4 Specimen Height

The discussion in Section 3.3 indicates that compacting laboratory samples to heights greater than 62 mm might be desirable in some mixtures to prevent the need to use gyrations in excess of Ndes that decrease the CT Index, thus potentially decreasing the number of outlying observations. Conceptually, as long as the volume tested is representative of the material, the results of any indirect-tension-based tests, such as the IDEAL-CT, should not depend on the specimen thickness as both the thickness and the diameter are accounted for in the calculations. According to ASTM D8225, for laboratory compacted samples using mixtures with a nominal maximum aggregate size, NMAS, of 19 mm or smaller, the specimen shall be 150 ± 2 mm in diameter and 62 ± 1 mm in thickness. However, the same standard provides the following equation to calculate the CT Index:

$$CT_{index} = \frac{t}{62} x \frac{l_{75}}{D} x \frac{G_f}{|m_{75}|} x 10^6$$

Where:

G_f = failure energy in Joules/m^2
$|m_{75}|$ = absolute value of post-peak slope
l_{75} = displacement at 75% post peak load in mm
D = specimen diameter in mm
t = specimen thickness in mm

From the CT Index equation, it is clear that specimen thickness is already part of the calculations and that a height of 62 mm was chosen for factors other than the mechanics of materials. Nonetheless, to verify that the CT Index of specimens with a height of 62 mm is the same as the CT Index of specimens with a height of 75 mm (i.e., specimen height does not matter in the results), a Student's t-test assuming equal variances was performed on the data with the results shown on Table 3-4. As was mentioned in Section 3.3, those specimens that required more than 75 gyrations were considered questionable under some circumstances and were excluded from the analysis.

Table 3-4 Analysis of Specimen Height

		62 mm	***75 mm***	**Conclusion**
Staker	Mean	90.4	96.5	
	Variance	408.66	456.62	
	Observations	19	32	
	t-Stat	-0.9970		
	t-critical (2-tail)	2.0095		
	p(T≤t) two tail	0.3237		p > 0.05 fail to reject
Geneva	Mean	114.8	125.7	
	Variance	774.80	1010.58	
	Observations	5	11	
	t-Stat	0.6576		
	t-critical (2-tail)	2.1447		
	p(T≤t) two tail	0.5215		p > 0.05 fail to reject
Kilgore	Mean	194.8	171.9	
	Variance	2512.93	1153.69	
	Observations	19	28	
	t-Stat	1.876		
	t-critical (2-tail)	2.014		
	p(T≤t) two tail	0.0683		p > 0.05 fail to reject

The results presented in Table 3-4 confirm the theory and show that there is no statistical difference in the CT Index for specimens compacted to a thickness of 62 mm or 75 mm. Furthermore, there is no clear pattern indicating that one or the other would result in higher CT Index or higher variance. In fact, based on the mechanics of materials, any thickness between those values, or perhaps even thicker, is acceptable. This is clearly reflected in the equation shown in ASTM D8225. It is recognized that samples cored from asphalt pavements might be thinner. In those cases, ASTM D8225 states that the minimum thickness should be 38 mm.

3.5 Effect of Air Voids

It is known that the air void content affects asphalt mixture properties. While ASTM D8225 does not specifically require a target air void content, it states that a typical target value is 7.0%. It also states that while other target air voids can be used, specimens with a difference in air voids greater than ± 0.5% are not comparable.

While Table 1-1 does not identify air voids as a variable in this study, the practicalities of sample compaction resulted in some samples with air voids outside the typical 7.0 ± 0.5 percent target. To evaluate the effect of air voids on the CT Index, the values were plotted and a trend was determined. Figures 3-3, 3-4, and 3-5 show the effect of air voids for each of the three mixtures tested for samples compacted to less than 75 gyrations.

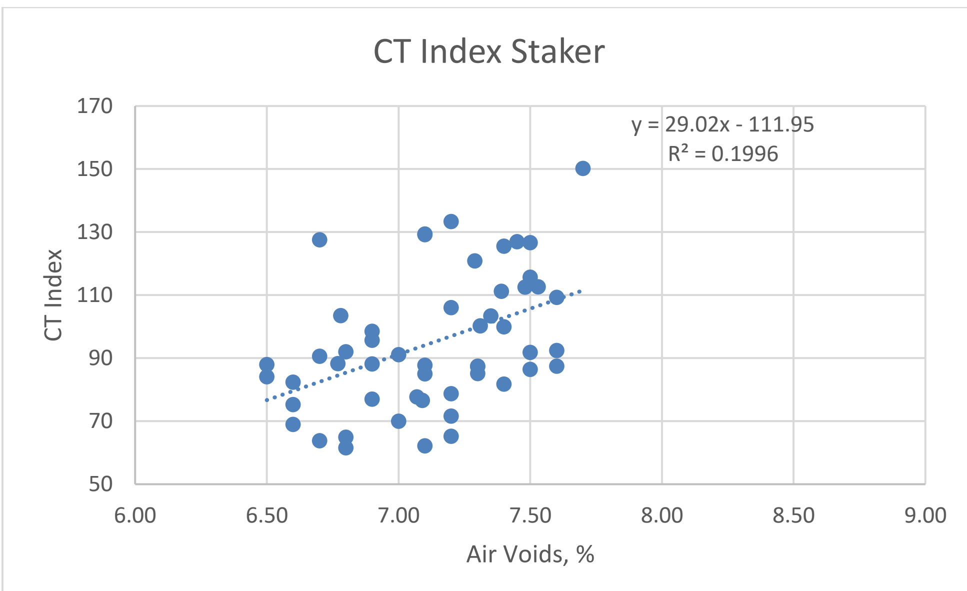

Figure 3-3 Effect of Air Voids on CT Index for Staker Mix

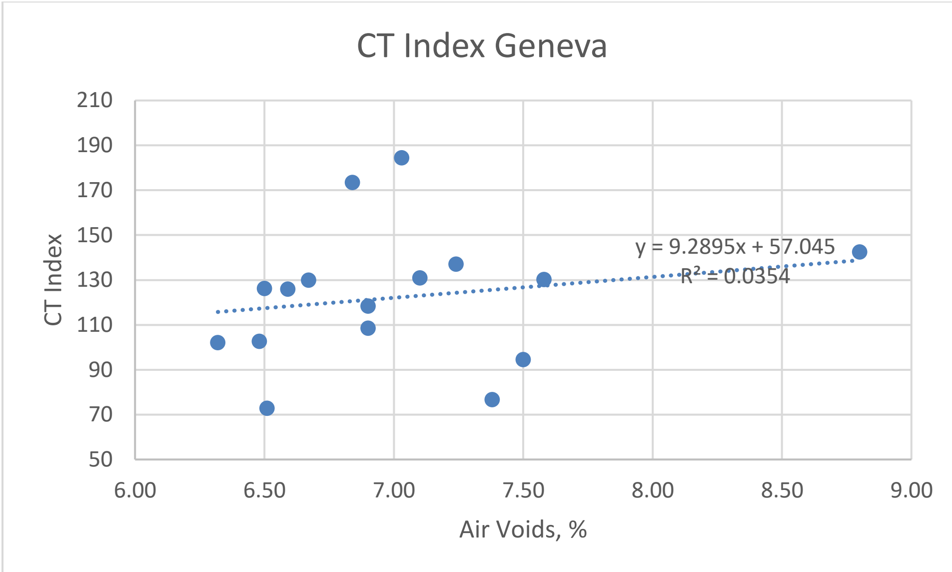

Figure 3-4 Effect of Air Voids on CT Index for Geneva Mix

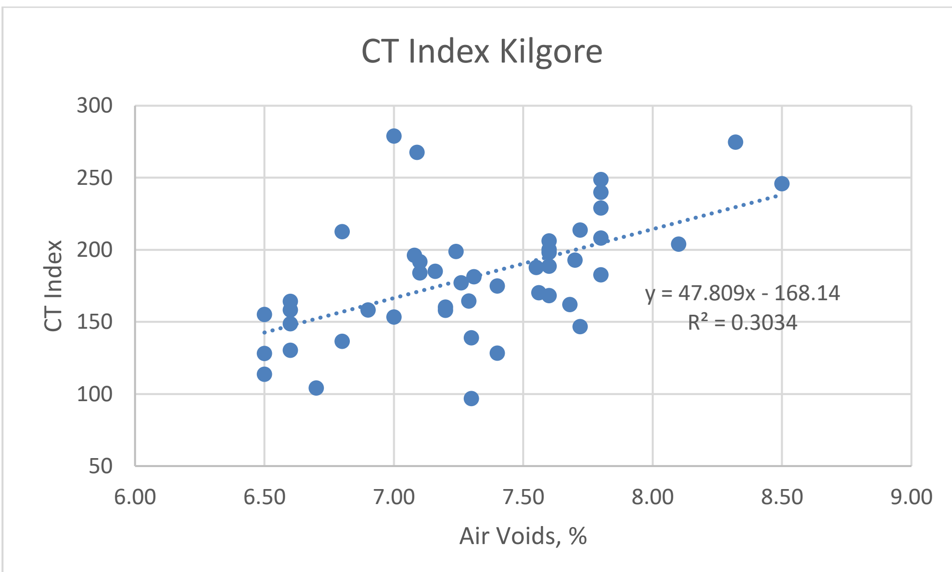

Figure 3-5 Effect of Air Voids on CT Index for Kilgore Mix

Figures 3-3 through 3-5 show that the vast majority of the data fell within the target air void values of 7.0 ± 0.5 percent. Only two data points fell below the 6.5% lower limit, twenty-one fell between 7.5% and 7.8%, and four had air voids above 8.0%. This limited number of data points outside the range might not be enough to draw definite conclusions regarding a limit for testing (e.g., should samples with 7.8% air voids be accepted?). The correlation coefficient between air voids and CT Index ranged from a low of 0.19 to a high of 0.55 indicating a weak correlation. Nonetheless, the correlation is positive indicating that higher air voids result in higher CT Index values. As seen in Figures 3-3 through 3-5, the magnitude of this change is mixture-dependent. For example, using the trend developed in Figure 3-5, samples with 7.5% air voids have CT Index values of 190 while samples with 7.8% air voids have CT Index values of 205; using the trend developed in Figure 3-4, the same change in air voids results in an increase of the CT Index from 126 to 129. The significance of these changes will depend on how the data is being used. If the objective is to simply rank mixtures, then air voids outside 7.5% would not change the results. On the other hand, if a specific limit, or threshold, in the CT Index is ever created, then it is possible that having air voids outside the 7.5% upper limit might "push" the CT Index over the edge. However, even in the most sensitive mix, the increase in CT Index caused by air voids is less than the overall variability of the test.

3.6 Summary

Based on the analysis of the data, the following was found:

- The data can be reasonably assumed to be normally distributed with some outliers affecting its normality. The coefficient of variation for all results was found to be around 25 percent before any outliers were identified.

- Different mixtures resulted in different populations of the CT Index indicating that the test is able to distinguish between mixtures from different suppliers. Since no performance data is available and no threshold value of CT Index has been determined, no statement is made regarding how any of these mixtures would perform if placed on a road.

- When samples are compacted using a number of gyrations that exceeds their N_{design} (75 gyrations in this case), the quality of the data can be compromised. Greater reliability in the results was found if samples that required more than 75 gyrations to reach the target height are excluded from the analysis.

- The height of the specimen is accounted for in the calculations and has no effect on the CT Index; therefore, the height of the sample (62 mm or 75 mm) is not considered a variable. However, most of the samples that required more than 75 gyrations to reach compaction had a height of 62 mm. This implies that, for some mixtures, samples should be compacted to a height of 75 mm.

- The sensitivity of air voids on the CT Index is mixture-dependent, but higher air voids result in higher CT Index. Air voids as high as 7.8% were included in this analysis.

4.0 LABORATORY EVALUATION

4.1 Overview

In Chapter 3 the variables that affect the quality of the data were discussed. It was found that the mixtures should be treated separately. It was also found that sample height is already accounted for in the calculations for the CT Index. Based on these findings, the results for each mix are presented separately, and values obtained from samples of different heights were combined. This chapter evaluates the within- and between-lab variability of the data.

4.2 Individual Laboratory Data

The data was separated by the different participant labs. After eliminating the data from samples requiring more than 75 gyrations to compact, each lab had a different number of samples. The results are presented in Table 4-1.

Table 4-1 CT Index for Each Lab and Mix

		PEPG	UDOT	U of U	Pooled*
Staker	Mean	101.5	79.9	108.5	94.8
	Standard Deviation	16.63	11.89	21.87	17.00
	As a % of Mean	16.4	14.9	20.2	17.9
	n	12	22	18	52
	95% CI Max†	111.9	85.2	119.3	
	95% CI Min†	91.0	74.6	97.7	
Kilgore	Mean	135.4	191.0	202.3	181.2
	Standard Deviation	22.41	28.08	41.54	32.78
	As a % of Mean	16.6	14.7	20.5	18.1
	N	12	17	18	47
	95% CI Max†	149.5	205.4	222.6	
	95% CI Min†	121.3	176.6	181.7	
Geneva	Mean	119.26	--	122.9	122.3
	Standard Deviation	11.23	--	33.32	30.43
	As a % of Mean	9.4	--	27.7	24.9
	n	3	0	13	16
	95% CI Max†	139.9		142.9	
	95% CI Min†	98.6		102.9	

*Pooled values based on a weighted variance for standard deviation and a weighted mean
†Maximum and minimum values expected with 95% confidence

For each of the three mixtures tested and for each lab, Table 4-1 shows the average CT Index obtained, the variability in the results (standard deviation), the number of valid samples, and the CT Index range expected based on a 95% confidence interval.

Of interest is the fact that for each mixture, there is one lab which shows results that are different than the other two labs (values shown in red). It is not always the same lab, so it is not a consistent bias and is independent of the variability. For the Staker mix, the UDOT lab seems to have different CT Index values when compared to the other two labs; but, for the Kilgore mix, it is the PEPG lab with different CT Index values. Only two labs have valid data for the Geneva mix, but their results are fairly close to each other. This behavior seems random and no explanation was found.

An easy way to display the results is through a box-and-whisker plot. In this type of plot, the mean and median of the data are shown inside the box; the edges of the box indicate the upper and lower quartile of the data. The whiskers represent the extremes. The plots for each mix are shown in Figures 4-1 through 4-3.

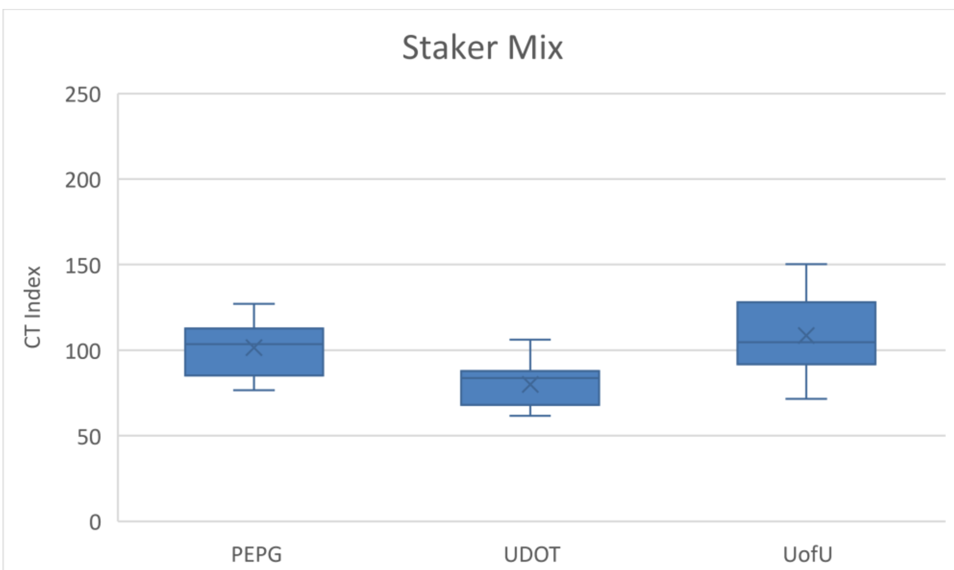

Figure 4-1 Box-and-Whisker Plot for the Staker Mix

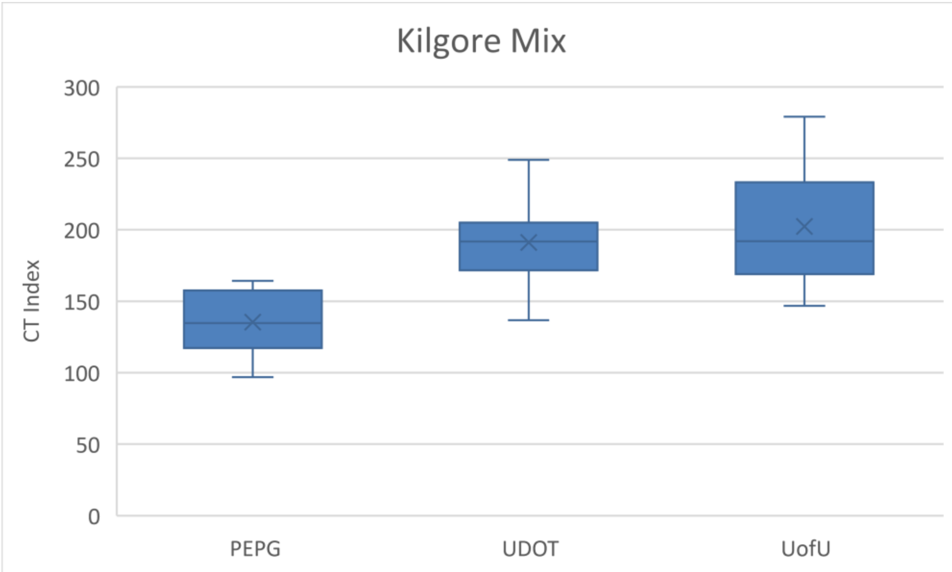

Figure 4-2 Box-and-Whisker Plot for the Kilgore Mix

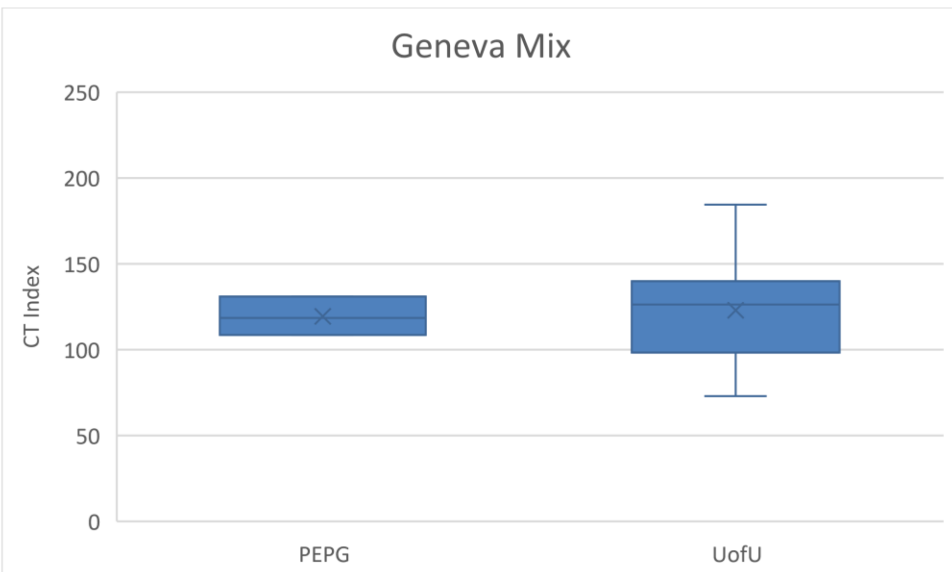

Figure 4-3 Box-and-Whisker Plot for the Geneva Mix

4.2.1 Within-Lab Variability

According to ASTM D670, the within-lab (single operator) standard deviation is defined as *"the standard deviation (or Coefficient of Variation) of test determinations obtained on identical test specimens by a single operator using the same apparatus in the same laboratory over a relatively short period of time. This value is equal to the pooled standard deviation of test* *determinations obtained by each operator. The coefficient of variation (ratio of standard deviation to the average expressed as a percentage) is used if the standard deviation is proportional to the level of the characteristic being measured. The within lab (single-operator) value, usually considered a property of the test method, will generally be lower than the multi-laboratory value."*

To determine the within-lab variability, the pooled coefficient of variation from each lab was obtained by calculating the weighted coefficient of variation shown in Table 4-1 across the three different mixtures. The results are shown in Table 4-2.

Table 4-2 Within-Lab Variability

Laboratory	Coefficient of Variation* Percent
PEPG	15.7
UDOT Central	14.8
U of U	22.3

* Pooled across all mixtures

Two of the labs show that the coefficient of variation within lab is about 15%. One lab shows values of 22%. The reason for this one lab showing a larger coefficient of variation is unknown.

4.2.2 Between-Lab Variability

According to ASTM C670, the between-lab (multi-laboratory) standard deviation is defined as "*the standard deviation or coefficient of variation of test results obtained with the same test method on identical test specimens in different laboratories with different operators using different equipment. The multi-laboratory standard deviation, or coefficient of variation, is the fundamental statistic underlying the indexes of precision under multi-laboratory conditions. The multi-laboratory standard deviation is an indication of the variability of a group of test results obtained by different laboratories for identical test specimens*."

The between-lab variability is the coefficient of variation for each mix across the different labs. In other words, it is the variance (standard deviation) of the means between labs from Table 4-1. These values for each mix are shown in Table 4-3.

Table 4-3 Between-Lab Variability

Mixture	Standard Deviation	Coeff. of Variation* Percent
Staker	14.91	15.7
Kilgore	35.81	19.8
Geneva†	--	--

* Percent based on pooled mean shown in Table 4-1

†Only two labs had valid data

4.2.3 Testing Implications

Knowing the within- and between-lab variability provides an estimate of the reliability of the CT Index and helps in selecting a testing protocol for mix evaluation. From a practical point of view, it is unrealistic for a routine test to require a large number of replicate samples; in most cases this number is 3 to 5 samples (with the lower number always preferred).

Considering the practical implications and following other material specifications, it is reasonable to require testing of 3 samples as long as the coefficient of variation from those specimens is below 15% (the within-lab variability described in Section 4.2.1). If the variability in the test outcome results in a coefficient of variation above 15%, then a review of the process should be done. If it is found that the high variability derives from one sample, then a fourth sample should be compacted and tested, and the outlier should be eliminated. It is acknowledged that going through the mixing, compaction, and testing of just one sample would create logistical difficulties. Therefore, for practical purposes, it is recommended that, as part of routine procedures, four samples be prepared, compacted and tested from a given mix. The average of the closest three can be used to determine the CT Index and the corresponding variability. If the coefficient of variation exceeds 15% and a single outlier cannot be identified, a new set of samples should be prepared and tested.

4.2.4 Quality Control and Acceptance

The process of quality control and acceptance might require the comparison of results between two different laboratories. Table 4-3 shows that the between-lab coefficient of variation is between 16% and 20%. If two labs cannot obtain results within reasonable variability, a referee lab should be used.

4.3 Summary

This chapter presents the results of the CT Index separated by the different laboratories. From the data presented, the within- and between-laboratory variability was determined. Based on the results, the following was found:

- Out of three participant labs, one of them had results that were significantly lower than the other two. It was not always the same laboratory; thus, a bias could not be established. The reason for this difference is not known.
- The within-lab variability, expressed as a coefficient of variation, was determined to be 15%. One of the labs had higher variability resulting in a coefficient of variation of 22%.
- Considering the variability of the results and the practical implications of laboratory testing, it was recommended that, for mixture evaluation, four samples be prepared, compacted, and tested. For the value to be valid, the coefficient of variation of the closest three values should be below 15%.
- The between-lab variability, expressed as a coefficient of variation was determined to be between 16% and 20%.
- The variability in the results seems to be mixture-dependent with some mixtures showing a higher level of variability in the results.

5.0 CONCLUSIONS AND RECOMMENDATIONS

5.1 Summary of Results

The goal of Phase VI of this series of studies is to determine whether the IDEAL-CT test was repeatable and under what conditions repeatability was optimized. This goal was accomplished where within-lab repeatability was determined to have a coefficient of variation less than 15% and the between-laboratory coefficient of variation less than 20%. These measures of variation can be achieved by eliminating outliers and paying attention to voids and gyration counts.

This success fulfills some of the goals for a test set forth by the Department which include:

- Fairly quick to perform: meets goal
- Precision: meets goal (within-lab CV < 15%)
- Repeatable: meets goal (between-lab CV <20%)
- Simple: meets goal
- Inexpensive: meets goal

The goal of having meaning has yet to be demonstrated. In Phase V of this series (Romero, 2021), a set of field samples were taken from the plant and from the windrow. No correlation could be found between different cracking indices nor could field performance be correlated.

At this point, it is known that the test is sensitive to binder quantity, RAP quantity, binder grade, binder modification, and aging (Zhou et al., 2017).

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5.2 Recommendations

The goal of this research was to determine the repeatability of the IDEAL-CT test and to find the issues that resulted in variability. Three mixes in common use in Utah were tested in three experienced laboratories, and the results were investigated to determine factors affecting repeatability.

To apply the statistics of central tendency, the test results must be normally distributed. This was found to be true; however, normalcy was improved with some trimming of identified outliers. The following is a discussion of the factors leading to possible non-normal behavior.

5.2.1 Number of Gyrations

When the number of gyrations needed to compact the sample to the height required exceeds Ndes (75 for the mixtures tested), it appears from observation of the broken faces and from the test result that the aggregates in the sample are damaged. This damage leaves uncoated faces in the matrix which increases variability. It is recommended that when the number of gyrations for the given height exceeds Ndes, the sample be rejected and the height be increased.

5.2.2 Specimen Height

The derivation of the CT Index includes parameters which adjust for the size of the sample. There was no difference in the calculated index with either 62-mm or 75-mm sample heights. It was found that when a 62-mm target height exceeded 75 gyrations, the sample target height could be increased and the number of gyrations could be reduced.

It is recommended that, if the number of gyrations to reach this height exceeds 75 (or Ndes), the target sample height be increased as needed up to 80 mm. It is also advised that a sample cut from the road may be at least 38 mm in height.

5.2.3 Repeatability

It was found that after trimming the data for outliers caused by high air voids and excess gyrations, the data behaved in a more normal fashion. Results settled down such that with three replicates, the laboratories could obtain within-lab repeatability CV of 15% and a between-lab

CV of 20%. Given the practicality of making another sample after finding an anomaly, it is recommended that four samples be produced and the result farthest from the mean be discarded. The remaining three samples should be averaged to obtain the final result.

5.3 Limitations and Challenges

It is clear that the IDEAL-CT test meets a majority of the criteria set out by the Department for adoption. The test has been shown to be sensitive to RAP content, binder content, binder grade, binder modification, and mix aging. The remaining issue is to tie the index to pavement performance. Since it is unknown what the target CT Index should be for any environmental or loading condition, caution should be used in applying any standard. There is some disparity in the data collected for this series of research projects between higher CT Index and better durability.

It is recommended that short- and long-term aged mixes should be evaluated using the CT Index and roadways using these mixes be observed for performance over a period of time before including the CT Index in a specification. The rate of aging should play a role in decisions of mix acceptability.

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APPENDIX A: DATA

Mix	Lab	Height, mm	Sample ID	Gyrations	Voids, %	CT Index
Staker	UDOT	62	Puck 1	41	7.50	91.90
Staker	UDOT	62	Puck 2	43	6.50	88.00
Staker	UDOT	62	Puck 3	49	6.60	75.30
Staker	UDOT	62	Puck 4	44	6.60	69.00
Staker	UDOT	62	Puck 5	41	6.80	61.60
Staker	UDOT	62	Puck 6	39	6.90	88.20
Staker	UDOT	62	Puck 7	31	7.20	106.10
Staker	UDOT	62	Puck 8	39	6.60	82.40
Staker	UDOT	62	Puck 9	28	7.40	81.80
Staker	UDOT	62	Puck 10	34	7.00	70.00
Staker	UDOT	62	Puck 11	45	6.80	64.90
Staker	UDOT	75	Puck 1	25	7.20	65.20
Staker	UDOT	75	Puck 2	24	7.10	85.00
Staker	UDOT	75	Puck 3	24	7.50	86.50
Staker	UDOT	75	Puck 4	33	7.00	91.10
Staker	UDOT	75	Puck 5	35	6.90	77.00
Staker	UDOT	75	Puck 6	30	7.30	85.20
Staker	UDOT	75	Puck 7	30	7.10	62.20
Staker	UDOT	75	Puck 8	24	7.30	87.40
Staker	UDOT	75	Puck 9	25	7.10	87.80
Staker	UDOT	75	Puck 10	31	6.70	63.80
Staker	UDOT	75	Puck 11	28	7.30	87.50
Staker	UofU	62	Puck 1	53	7.10	129.40
Staker	UofU	62	Puck 2	57	6.80	92.10
Staker	UofU	62	Puck 3	61	6.70	90.60
Staker	UofU	62	Puck 4	55	6.70	127.60
Staker	UofU	62	Puck 5	64	6.90	98.60
Staker	UofU	62	Puck 6	73	7.50	126.70
Staker	UofU	62	Puck 7	70	6.90	95.70
Staker	UofU	62	Puck 8	63	7.20	78.80
Staker	UofU	62	Puck 9	53	7.40	125.60
Staker	UofU	75	Puck 1	36	7.20	71.60
Staker	UofU	75	Puck 2	35	7.60	87.50
Staker	UofU	75	Puck 3	34	7.40	100.00
Staker	UofU	75	Puck 4	34	7.60	109.30
Staker	UofU	75	Puck 5	35	7.70	150.20
Staker	UofU	75	Puck 6	38	7.60	92.50
Staker	UofU	75	Puck 7	41	7.20	133.40
Staker	UofU	75	Puck 8	36	7.10	129.20
Staker	UofU	75	Puck 9	30	7.50	115.70

Mix	Lab	Height, mm	Sample ID	Gyrations	Voids, %	CT Index
Staker	PEPG	62	sp1 62	108	7.49	123.90
Staker	PEPG	62	sp2 62	161	6.91	52.60
Staker	PEPG	62	sp3 62	133	6.91	110.30
Staker	PEPG	62	sp4 62	129	6.52	84.00
Staker	PEPG	62	sp562	125	6.66	64.50
Staker	PEPG	62	sp6 62	140	6.54	45.90
Staker	PEPG	62	sp7 62	103	6.52	43.50
Staker	PEPG	62	sp8 62	125	6.90	74.60
Staker	PEPG	62	sp9 62	161	6.53	74.30
Staker	PEPG	75	sp1 75	53	7.07	77.70
Staker	PEPG	75	sp2 75	48	7.48	112.60
Staker	PEPG	75	sp3 75	68	7.29	120.90
Staker	PEPG	75	sp4 75	44	7.53	112.70
Staker	PEPG	75	sp5 75	48	7.45	127.00
Staker	PEPG	75	sp6 75	31	7.35	103.40
Staker	PEPG	75	sp7 75	40	7.09	76.60
Staker	PEPG	75	sp8 75	35	7.31	100.30
Staker	PEPG	75	sp9 75	43	6.78	103.50
Staker	PEPG	75	sp10 75	53	7.39	111.20
Staker	PEPG	75	sp12 75	48	6.77	88.30
Staker	PEPG	75	sp13 75	67	6.50	84.10
Geneva	UDOT	62	Puck 1	271	6.90	55.40
Geneva	UDOT	62	Puck 2	196	7.20	87.70
Geneva	UDOT	62	Puck 3	133	7.10	129.20
Geneva	UDOT	62	Puck 4	299	7.50	83.70
Geneva	UDOT	62	Puck 5	206	7.20	106.60
Geneva	UDOT	62	Puck 6	189	7.40	90.60
Geneva	UDOT	62	Puck 7	299	7.10	85.60
Geneva	UDOT	62	Puck 8	201	7.20	136.50
Geneva	UDOT	62	Puck 9	205	7.50	102.10
Geneva	UDOT	75	Puck 1	109	6.50	71.50
Geneva	UDOT	75	Puck 2	146	6.70	80.90
Geneva	UDOT	75	Puck 3	99	7.00	105.50
Geneva	UDOT	75	Puck 4	112	7.10	80.30
Geneva	UDOT	75	Puck 5	131	6.60	99.00
Geneva	UDOT	75	Puck 6	89	7.00	72.20
Geneva	UDOT	75	Puck 7	190	6.90	98.10
Geneva	UDOT	75	Puck 8	134	7.30	128.00
Geneva	UDOT	75	Puck 9	106	7.50	126.80
Geneva	UofU	62	Puck 1	61	8.80	142.50
Geneva	UofU	62	Puck 2	64	7.50	94.50
Geneva	UofU	62	Puck 3	89	7.54	100.20
Geneva	UofU	62	Puck 4	84	7.42	105.70
Geneva	UofU	62	Puck 5	76	7.70	141.20

Mix	Lab	Height, mm	Sample ID	Gyrations	Voids, %	CT Index
Geneva	UofU	62	Puck 6	72	7.38	76.70
Geneva	UofU	62	Puck 7	80	7.26	116.10
Geneva	UofU	62	Puck 8	79	7.81	111.10
Geneva	UofU	62	Puck 9	72	7.58	130.20
Geneva	UofU	75	Puck 1	68	6.67	130.00
Geneva	UofU	75	Puck 2	56	7.03	184.40
Geneva	UofU	75	Puck 3	38	6.51	72.90
Geneva	UofU	75	Puck 4	58	6.48	102.60
Geneva	UofU	75	Puck 5	48	6.59	125.90
Geneva	UofU	75	Puck 6	52	7.24	137.10
Geneva	UofU	75	Puck 7	46	6.84	173.40
Geneva	UofU	75	Puck 8	56	6.50	126.20
Geneva	UofU	75	Puck 9	45	6.32	102.10
Geneva	PEPG	62	m1 62	174	6.50	76.50
Geneva	PEPG	62	m2 62	238	6.20	59.80
Geneva	PEPG	62	m3 62	184	6.60	73.00
Geneva	PEPG	62	m4 62	175	6.80	77.70
Geneva	PEPG	62	m5 62	186	6.50	115.70
Geneva	PEPG	62	m6 62	171	7.10	69.70
Geneva	PEPG	62	m7 62	183	6.80	83.40
Geneva	PEPG	62	m8 62	186	6.50	59.30
Geneva	PEPG	75	m1 75	92	7.40	182.60
Geneva	PEPG	75	m2 75	67	7.10	130.90
Geneva	PEPG	75	m3 75	72	6.90	108.50
Geneva	PEPG	75	m4 75	74	6.90	118.40
Geneva	PEPG	75	m5 75	80	6.80	106.10
Geneva	PEPG	75	m6 75	87	7.00	119.70
Geneva	PEPG	75	m7 75	77	7.10	163.70
Geneva	PEPG	75	m8 75	77	7.00	90.80
Geneva	PEPG	75	m9 75	81	7.00	98.80
Kilgore	UDOT	62	Puck 1	89	6.60	167.70
Kilgore	UDOT	62	Puck 2	37	7.80	248.80
Kilgore	UDOT	62	Puck 3	58	7.60	168.30
Kilgore	UDOT	62	Puck 4	69	7.80	239.80
Kilgore	UDOT	62	Puck 5	50	7.80	182.70
Kilgore	UDOT	62	Puck 6	45	8.10	204.00
Kilgore	UDOT	62	Puck 7	107	6.90	139.40
Kilgore	UDOT	62	Puck 8	58	7.60	198.20
Kilgore	UDOT	62	Puck 9	60	7.40	175.00
Kilgore	UDOT	75	Puck 1	52	6.80	136.60
Kilgore	UDOT	75	Puck 2	47	7.20	160.20
Kilgore	UDOT	75	Puck 3	41	7.10	184.00
Kilgore	UDOT	75	Puck 4	50	7.10	191.70
Kilgore	UDOT	75	Puck 5	54	6.80	212.60

Mix	Lab	Height, mm	Sample ID	Gyrations	Voids, %	CT Index
Kilgore	UDOT	75	Puck 6	38	7.60	206.20
Kilgore	UDOT	75	Puck 7	39	7.60	200.10
Kilgore	UDOT	75	Puck 8	49	7.20	158.00
Kilgore	UDOT	75	Puck 9	37	7.70	192.80
Kilgore	UDOT	75	Puck 10	36	7.60	188.70
Kilgore	UofU	62	Puck 1	39	7.80	229.00
Kilgore	UofU	62	Puck 2	31	8.32	274.70
Kilgore	UofU	62	Puck 3	35	7.08	196.20
Kilgore	UofU	62	Puck 4	32	7.72	146.70
Kilgore	UofU	62	Puck 5	27	7.72	213.70
Kilgore	UofU	62	Puck 6	34	7.00	153.40
Kilgore	UofU	62	Puck 7	21	8.50	245.90
Kilgore	UofU	62	Puck 8	36	7.00	279.00
Kilgore	UofU	62	Puck 9	33	7.31	181.30
Kilgore	UofU	75	Puck 1	32	7.16	185.10
Kilgore	UofU	75	Puck 2	31	7.24	198.80
Kilgore	UofU	75	Puck 3	33	7.09	267.60
Kilgore	UofU	75	Puck 4	30	7.55	187.70
Kilgore	UofU	75	Puck 5	34	7.29	164.60
Kilgore	UofU	75	Puck 6	31	7.26	177.20
Kilgore	UofU	75	Puck 7	29	7.68	162.10
Kilgore	UofU	75	Puck 8	32	7.80	208.20
Kilgore	UofU	75	Puck 9	30	7.56	170.30
Kilgore	PEPG	62	k1 62	85	7.10	187.40
Kilgore	PEPG	62	k2 62	76	7.20	119.30
Kilgore	PEPG	62	k3 62	95	7.10	193.80
Kilgore	PEPG	62	k4 62	82	7.00	149.60
Kilgore	PEPG	62	k562	75	7.30	96.90
Kilgore	PEPG	62	k6 62	58	7.40	128.30
Kilgore	PEPG	62	k7 62	58	7.30	138.90
Kilgore	PEPG	75	k1 75	60	6.60	164.30
Kilgore	PEPG	75	k2 75	68	6.60	130.30
Kilgore	PEPG	75	k3 75	60	6.50	155.10
Kilgore	PEPG	75	k4 75	61	6.70	104.10
Kilgore	PEPG	75	k5 75	64	6.50	113.60
Kilgore	PEPG	75	k6 75	63	6.60	148.70
Kilgore	PEPG	75	k7 75	56	6.50	128.20
Kilgore	PEPG	75	k8 75	65	6.60	158.30
Kilgore	PEPG	75	k9 75	63	6.90	158.30