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Evaluation of Repeatability of Kansas Test Method KT-73, "Density, Absorption and Voids in Hardened Concrete," Boil Test

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Kansas Department of Transportation
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KDOT has also used the Kansas Test Method KT-73 (2012), *Density, Absorption and Voids in Hardened Concrete*, a permeability test commonly referred to as the Boil Test, to evaluate concrete durability in the state of Kansas. It covers the determinations of density, percent absorption, and percent permeable voids in hardened concrete. KT-73 reflects testing procedures found in ASTM C642 (2013). KDOT has relied on this test to evaluate concrete permeability, but some concrete producers in the state have objected to its accuracy, preferring the Rapid Chloride Test which has a low repeatability. In 2009, with the help of several ready mix producers and private laboratories, KDOT conducted a round robin evaluation of KT-73.

The results of this round robin showed that the KT-73 Boil Test could be repeated with a fairly high degree of precision. This study demonstrates that the expected range between two properly conducted tests at different laboratories should not be more than 8% of the average. The repeatability of the Boil Test is significantly better than the repeatability of the Rapid Chloride Test for concrete cylinders, AASHTO T277 (2011), which many concrete producers have relied on to verify their concrete's durability. The Boil Test and the Rapid Chloride Test take about equal amounts of time to perform, but the equipment required for the Boil Test is significantly less expensive. Thus, the Boil Test is not only less expensive to perform, but is a better indicator with respect to reliability of the permeability and durability of concrete used in the state of Kansas.

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Final Report

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June 2015

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Abstract

For years, the Kansas Department of Transportation (KDOT) and concrete producers in the state have used a Rapid Chloride Test for concrete cylinders, AASHTO T277. This test has been thought of as an appropriate quality control test to evaluate permeability in concrete. Unfortunately, it has a low repeatability—a 51% difference in the mean between two laboratories/operators as percent of the mean (AASHTO T277, 2011). This could mean the difference between reliable permeability results and questionable results. This has a direct impact on KDOT's ability to judge the quality of the concrete mixture, and whether it will be a long-term durable concrete or a concrete that fails early.

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The results of this round robin showed that the KT-73 Boil Test could be repeated with a fairly high degree of precision. This study demonstrates that the expected range between two properly conducted tests at different laboratories should not be more than 8% of the average. The repeatability of the Boil Test is significantly better than the repeatability of the Rapid Chloride Test for concrete cylinders, AASHTO T277 (2011), which many concrete producers have relied on to verify their concrete's durability. The Boil Test and the Rapid Chloride Test take about equal amounts of time to perform, but the equipment required for the Boil Test is significantly less expensive. Thus, the Boil Test is not only less expensive to perform, but is a better indicator with respect to reliability of the permeability and durability of concrete used in the state of Kansas.

Acknowledgements

KDOT would like to thank the following laboratories for providing testing facilities and data for this round robin:

- Terracon—Topeka, KS
- Kleinfelder—Topeka, KS
- LaFarge Laboratory Kansas City Performance Center
- Alpha Omega GeoTech
- Monarch Cement
- Terracon—Lenexa, KS
- Kleinfelder—Lenexa, KS
- TetraTech
- Ash Grove Technical Center
- Professional Service Industries, Inc.
- Terracon—Wichita, KS
- Allied Laboratories
- Fordyce Concrete
- LaFarge—KS & MO Ready Mix
- Kansas DOT Materials Laboratory—Topeka, KS

KDOT would like to thank the following ready mix plants for providing concrete samples to be tested for this round robin:

- Midwest Concrete Materials
- LaFarge—KS & MO Ready Mix
- Fordyce Concrete
- LaFarge—Wichita, KS

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Introduction

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Seasoned Concrete Pavement Cores

In order to test the variability between laboratories and methodology, old seasoned concrete pavement cores were tested by several laboratories. A set of seasoned, well-aged (over 10 years old) concrete samples labeled #1 to #3 were sent to 13 different test facilities and tested for permeability using the Kansas Boil Test KT-73 (2012). It was found that the first three times the sample set was tested, the answers were almost identical. The fourth time the set was tested, the results increased and stayed consistent for the next five tests. It then jumped again and remained consistent for the next five tests (Figure 1). The age of the sample set was not a factor, since there were almost three months between the time the seventh laboratory tested the samples and when the eighth laboratory tested them—not to mention that the samples were more than 10 years old.

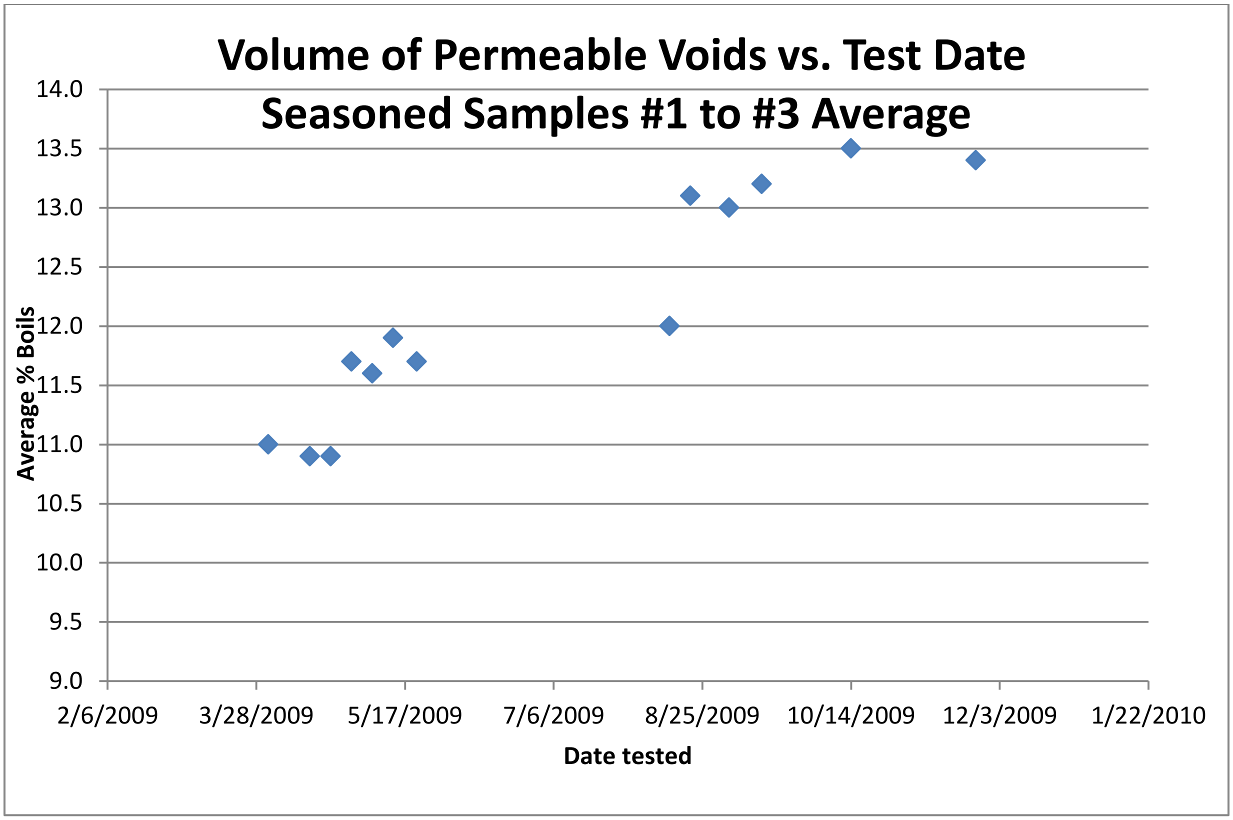


Figure 1: Volume of Permeable Voids vs. Test Date for Seasoned Samples #1 to #3

A second set of seasoned, well-aged (over 10 years old) concrete samples labeled #4 to #6 were also sent to the same 13 different test facilities and tested for permeability using KT-73 (2012). This sample set also experienced the similar increase in permeability as Samples #1 to #3 when the tests are repeated numerous times, although not to the same degree (Figure 2). Further testing would need to be done to differentiate why the permeability increases on the same sample set when the tests are repeated numerous times. The possibility that the sample set is degrading with increased testing should be looked at.

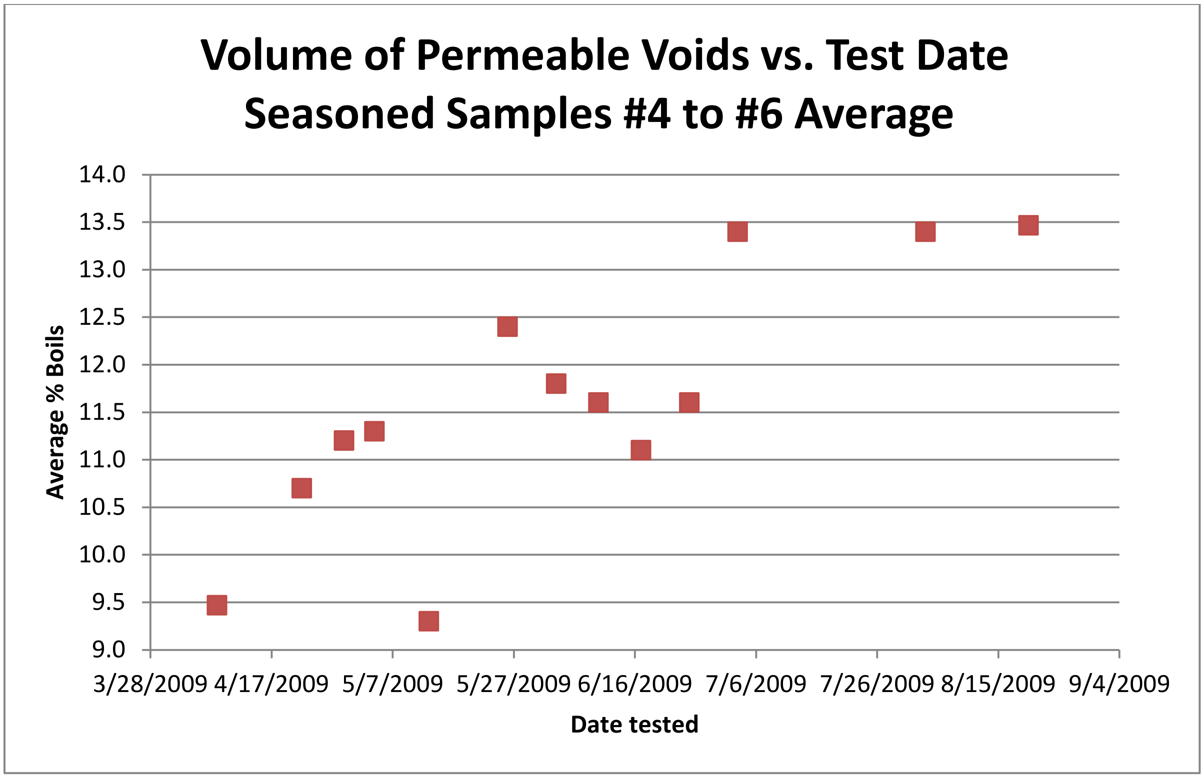


Figure 2: Volume of Permeable Voids vs. Test Date for Seasoned Samples #4 to #6

New Specimens Round Robin Criteria

In 2009, four different mixes were supplied by ready mix producers and the concrete cylinders were cast by technicians from a variety of laboratories. Detailed instructions were given for the casting requirements in order to minimize the variability in casting the specimens. The cylinders were then tested according to KT-73 (2012) by a variety of laboratories. Not all cylinders were tested by all of the participating laboratories. All testing was blind; no identification of the laboratory or ready mix supplier was noted on the final report. The intent of this round robin was to evaluate the consistencies and/or inconsistencies in performing the Kansas Test Method KT-73 Boil Test by different laboratories. KDOT hoped to show that the Boil Test could be replicated with a certain degree of precision between laboratories. Data were analyzed using guidance from ASTM C802 (2009). Testing procedures for the round robin can be found in Appendix A.

New Concrete Round Robin Results Mix #3

Twelve different laboratories received a set of three concrete cylinders made from Trial Mix #3 cast on April 1, 2009. The set of results from this mix was to test the variability between laboratories on specimens cast in the field from the same batch of concrete. The results from these tests range from 14.2% to 15.2% Boil, with an average 14.6% Boil and a standard deviation of 0.2578 (Table 1).

A set of three concrete cylinders from three other mix designs were tested by either four or five different laboratories. Since there were a smaller number of laboratories that tested these three mix designs (Mix #1, #2, and #4), there should have been a larger number of samples tested as recommended by ASTM C802 (2009). Even though this was not the case, the data is included in this study. (When only four or five laboratories participate in round robin tests, it is recommended that at least six to eight samples are tested by each laboratory; only three samples of each mix design were tested per laboratory in this round robin evaluation. Only two of the laboratories [a and b] tested all four mix designs [see Figure 3]. Mix designs are located in Appendix C.)

Table 1: Mix # 3 Boil Test Results

Lab #	Sample #	% Boil	Within Lab Average % Boil ($\bar{x}_i$)	Individual Range as % Avg
a	1	14.3		
	2	14.4		
	3	14.5	14.4	1.4
b	1	15.0		
	2	14.8		
	3	14.6	14.8	2.7
c	1	14.2		
	2	14.7		
	3	14.5	14.5	3.4
d	1	14.8		
	2	14.2		
	3	14.2	14.4	4.2
e	1	14.4		
	2	14.6		
	3	14.7	14.6	2.1
f	1	14.1		
	2	14.4		
	3	14.2	14.2	2.1
g	1	15.3		
	2	14.9		
	3	15.5	15.2	3.9
h	1	15.2		
	2	15.0		
	3	14.7	15.0	3.3
i	1	14.7		
	2	14.6		
	3	15.0	14.8	2.7
j	1	14.9		
	2	14.8		
	3	14.2	14.6	4.8
l	1	13.9		
	2	14.3		
	3	14.7	14.3	5.6
m	1	14.7		
	2	14.1		
	3	14.1	14.3	4.2
Average			14.6	
Range of Averages			1.0	
R as % Avg			6.9	
Rapid Chloride	Coulombs		2627.0	
Compressive Strength	PSI		5563	

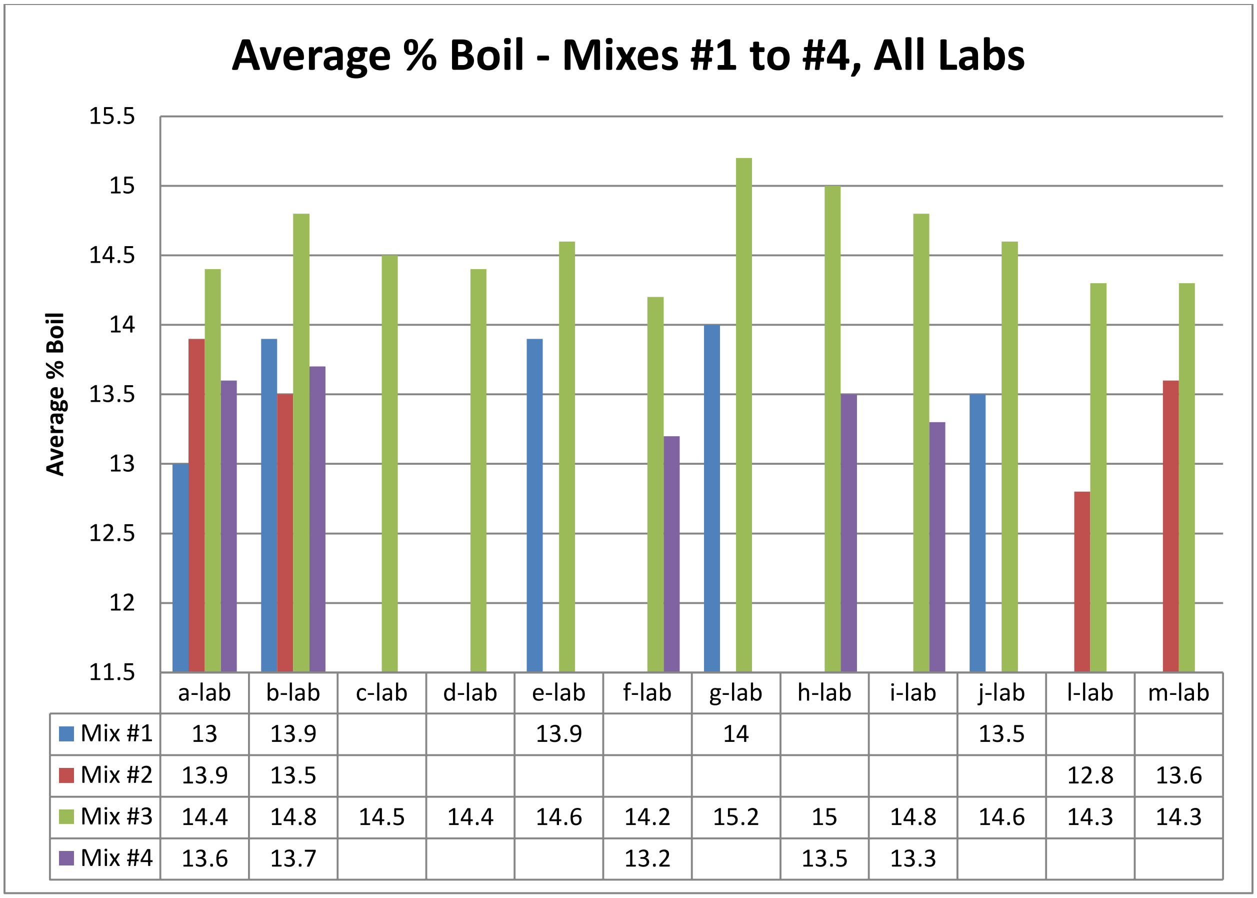
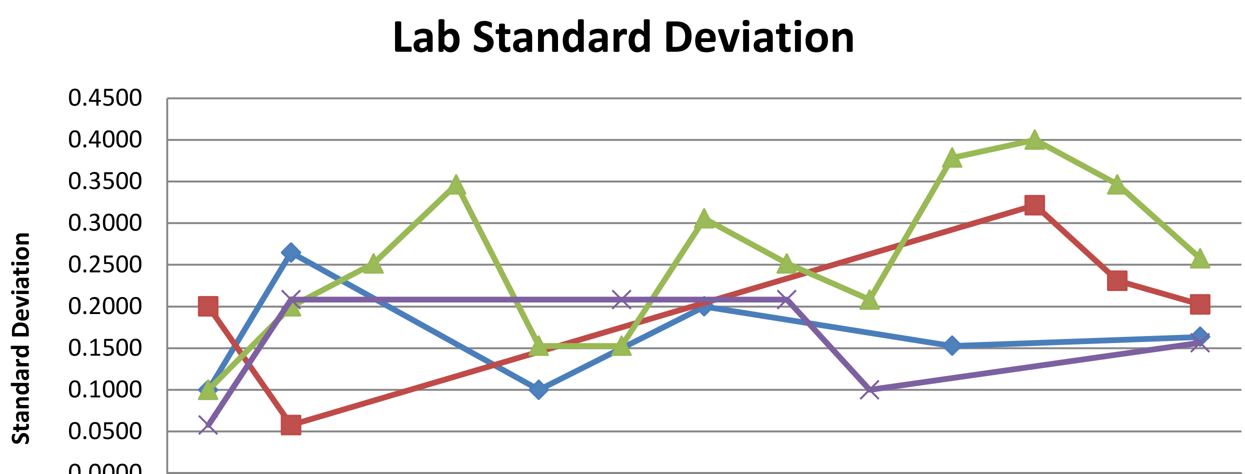


Figure 3: Percent Boil of Mixes #1 through #4

Although Mixes #1, #2, and #4 were only tested by four or five different laboratories, the results were consistent, as the standard deviation ranged from 0.1565 to 0.2025 (Figure 4). The average standard deviation for Mix #3 was 0.2578, which is consistent with the larger number of laboratories running the tests (Figure 4).



	a-lab	b-lab	c-lab	d-lab	e-lab	f-lab	g-lab	h-lab	i-lab	j-lab	l-lab	m-lab	Avg STD Dev
Mix #1	0.1000	0.2646			0.1000		0.2000			0.1528			0.1635
Mix #2	0.2000	0.0577									0.3215	0.2309	0.2025
Mix #3	0.1000	0.2000	0.2517	0.3464	0.1528	0.1528	0.3055	0.2517	0.2082	0.3786	0.4000	0.3464	0.2578
Mix #4	0.0577	0.2082				0.2082		0.2082	0.1000				0.1565

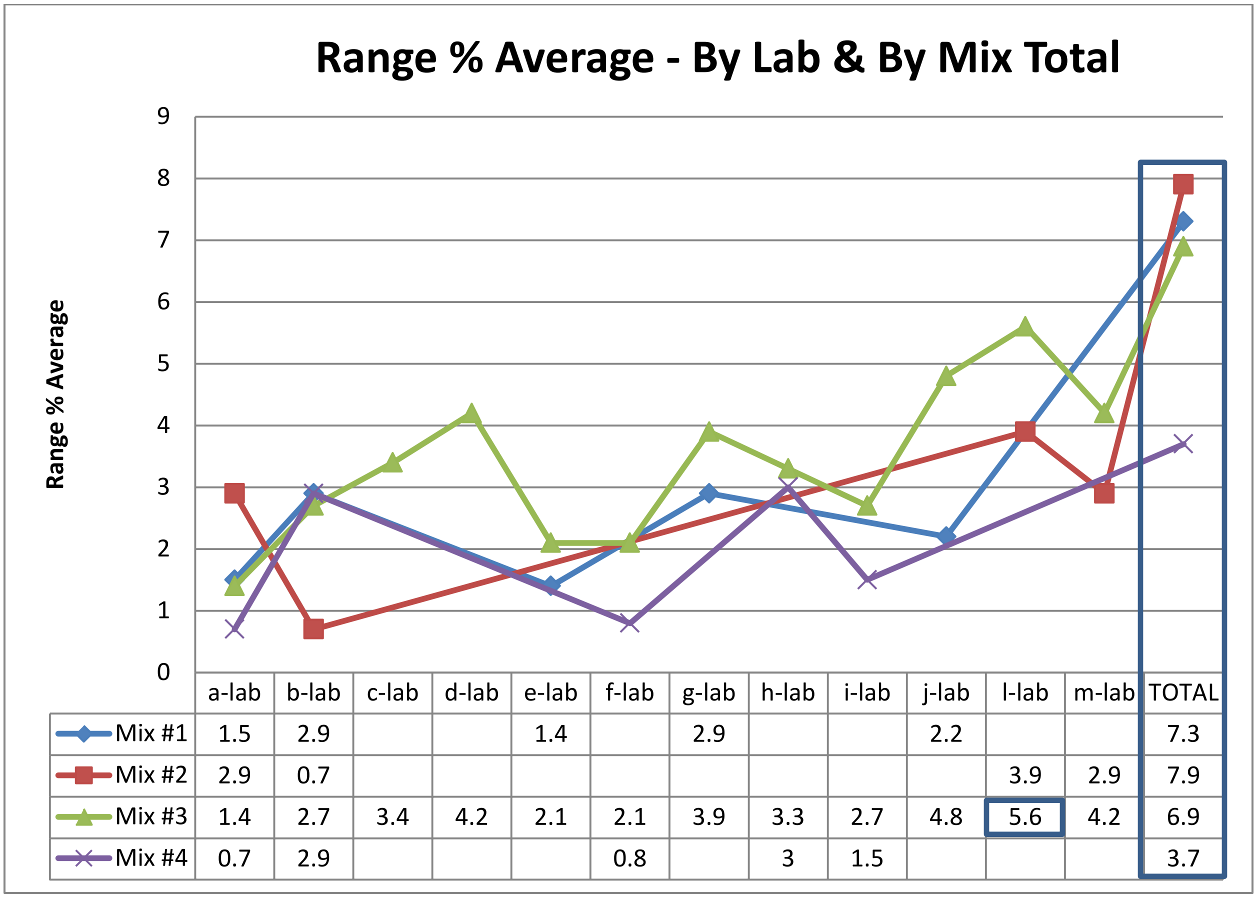
Figure 4: Laboratory Standard Deviation

Results and Conclusions

The results of this round robin showed that the KT-73 (2012) Boil Test could be repeated with a significant degree of precision within the laboratory and between different laboratories.

- Within Laboratory: This study demonstrates that the expected range of individual Boil Test results of three tests conducted in a single laboratory should not be more than 6% of the average of the three samples based on the test results of Mix #3 (Figure 5).
- Multi-Laboratory: This study demonstrates that the expected range between two properly conducted tests at different laboratories should not be more than 8% of the average. This is based on all four mixes tested (Figure 5).

The repeatability of the Boil Test (KT-73, 2012) is significantly better than the repeatability of the Rapid Chloride Test for concrete cylinders (AASHTO T-277, 2011), which only has 51% difference in the mean between two laboratories/operators as percent of the mean. Thus, the Boil Test, if performed correctly, would be a more reliable indicator of the permeability and durability of concrete used in the state of Kansas. The Boil Test is also significantly less expensive to perform than the Rapid Chloride Test.



	a-lab	b-lab	c-lab	d-lab	e-lab	f-lab	g-lab	h-lab	i-lab	j-lab	l-lab	m-lab	TOTAL
Mix #1	1.5	2.9			1.4		2.9			2.2			7.3
Mix #2	2.9	0.7									3.9	2.9	7.9
Mix #3	1.4	2.7	3.4	4.2	2.1	2.1	3.9	3.3	2.7	4.8	5.6	4.2	6.9
Mix #4	0.7	2.9				0.8		3	1.5				3.7

Figure 5: Range % Average for Boil Test

References

AASHTO Designation T277-11. (2011). Standard method of test for electrical indication of concrete's ability to resist chloride ion penetration. *Standard specifications for transportation materials and methods of sampling and testing* (24th ed.). Washington, DC: American Association of State Highway and Transportation Officials.

ASTM Standard C642-13. (2013). *Standard test method for density, absorption, and voids in hardened concrete*. West Conshohocken, PA: ASTM International. DOI: 10.1520/C0642-13, www.astm.org.

ASTM Standard C802-09a. (2009) *Standard practice for conducting an interlaboratory test program to determine the precision of test methods for construction materials*. West Conshohocken, PA: ASTM International. DOI: 10.1520/C0802-09A, www.astm.org.

KT-73 Kansas Test Method. (2012). Density, absorption and voids in hardened concrete. *Kansas Department of Transportation construction manual, part V*. Topeka, KS: Kansas Department of Transportation.

Appendix A: Round Robin Blind Testing Format

KDOT KT-73 (ASTM C642)

Each participating Ready Mix Producer will produce 1 batch of concrete (see guidelines below).

All specimens will be cast for KT-73 (ASTM C642) testing at the Ready Mix Producer's plant facility by each participating laboratory and KDOT representatives.

All results will be recorded and reported directly to KDOT.

KDOT will collect all data from each laboratory and submit a final report of all results to each laboratory involved. All testing will be blind. No identification of laboratory or supplier will be noted on final report.

<u>Ready Mix Producers Guidelines:</u>

-Select one mix for testing using KDOT approved materials

> Ready Mix #1- Produces a Recipe Mix with *NO* air and *NO* water reducer.
>
> Ready Mix #2- Produces a Recipe Mix OR an Optimized mix, with no other adjustments other than using less cement with the addition of an Air Entraining Agent AND a Water Reducer. *NO* SCM's!
>
> Ready Mix #3- Produces a Recipe Mix with NO Air Entraining Agent and Water Reducer, but does include a SCM's (Class F Fly Ash, Slag, Class C Fly Ash *IF* C1567 testing has been provided to KDOT for review. *NO* Silica Fume!)
>
> Ready Mix #4- Produces an Optimized Mix with a SCM or Ternary Mix (Class F Fly Ash, Slag, Class C Fly Ash *IF* C1567 testing has been provided to KDOT for review. *NO* Silica Fume!), with Air Entrainment and a Water Reducer.

Please submit proposed mix design to KDOT in advance for review prior to date of trial batch.

A copy of the batch ticket will be provided to KDOT as well.

Each Ready Mix Supplier will provide sufficient wheelbarrows for sampling and 4 x 8 molds for specimen preparation (45 specimens total per trial batch)
Coordinate with KDOT and TQC Chairman the date of trial batch for each location (Potential Dates are March 25th, April 1st, April 8th, and April 15th)

Trial batch one load and cast 3 cylinders x 13 laboratories
(39 + 6 for RCP and Compressive Strength=45 specimens total)

Standard cure for 24-48 hours (lime water 60-80°F)

Testing Laboratories:

-Receive samples
-Continue cure until 23 days (should fall on a Friday), dry sample over the weekend, soak the sample Monday and Tuesday, if weights are constant, begin boil on Wednesday.
-Note curing method
-Prepare specimens per method
-Conduct testing per KDOT KT-73 test method (ASTM C642)
    -Review KT-6, KT-22, KT-49, and KT-73, ask questions if unclear
    -Ensure water is rapidly boiling prior to putting specimen in water for test
    -Record Temperature of the water when samples are added
    -Record how long it took the water to start boiling again
    -All testing (submersion and boiling) shall be conducted with tap water

KDOT will also supply each laboratory with 6 specimens of “older” concrete for testing. KDOT would like to have each laboratory test each of these 6 specimens over a 13 week +/- period. The boiling should be done on Wednesday to allow for a 2 day soak, and 2 days to deliver the cores to the next lab in time for them to dry them back out over the weekend. This testing can begin immediately.

KDOT will provide each laboratory with a worksheet/checklist to record and report all results for clarity and consistency. All results will be forwarded to KDOT’s Central Laboratory in Topeka, KS, for preparation and distribution in a final report.

Appendix B: Kansas Test Method KT-73

5.9.73 DENSITY, ABSORPTION AND VOIDS IN HARDENED CONCRETE
(Kansas Test Method KT-73)

1. SCOPE

This method covers the determinations of density, percent absorption and percent voids in hardened concrete. **KT-73** reflects testing procedures found in **ASTM C 642**.

2. **REFERENCED DOCUMENTS**

2.1. Part V, 5.9; Sampling and Test Methods Forward

2.2. KT-22; Making and Curing Compression and Flexural Test Specimens in the Field

2.3. KT-49; Method for Obtaining and Testing Drilled Cores

2.4. ASTM C 642; Standard Test Method for Density, Absorption, and Voids in Hardened Concrete

3. APPARATUS

3.1. The balance shall conform to the requirements of **Part V, 5.9; Sampling and Test Methods Forward**, Class G5. The balance shall be equipped with suitable apparatus for suspending the sample container in water from the center of weighing platform or pan of the balance into a bucket with an overflow device to maintain a constant water level.

3.2. Container suitable for immersing the specimen and suitable apparatus for suspending the specimen in water. The container must be large enough to keep the specimens covered with boiling water for a period of 5 hours.

3.3. Forced draft oven capable of maintaining a temperature of 230 ± 9 °F (110 ± 5 °C).

4. TEST SPECIMEN

4.1. Prepare 3 samples per mix design. The samples shall consist of 2” thick by 4” diameter specimens taken from the top portion of cylinders or cores. Remove not more than 3/8” from the top of the cylinder or core and obtain the sample from the next 2”. Each portion shall be free from observable cracks, fissures, or shattered edges. Cylinders molded and cured in accordance with **KT -22** of this manual, shall be used for mix design approval and most verification samples. Cores obtained in accordance with **KT-49** of this manual, may be used for verifications on PCCP.

5. PROCEDURE Page 2/3 5.9.73 04-12 KT-73

Testing is usually scheduled so that the boiling of the samples takes place when the sample is between 27 and 29 days of age. Other timeframes may be required in the contract documents.

5.1. Determine the mass of each specimen. Place each specimen on its edge in a forced draft oven directly on the oven rack, and dry the sample at a temperature of 230 ±9 °F (110 ± 5 °C) for not less than 24 hours. Do not lay the specimens inside a pan, any other container. Do not lay the specimens on the flat surface of the cylinder. Allow enough room between samples for complete airflow around each sample. After removing each specimen from the oven, allow it to cool in dry air (preferably in a desiccator) to a temperature of 72 ± 5 °F (22 ± 3 °C) and determine the mass. If the specimen was comparatively dry when its mass was first determined, and the second mass agrees with the first within 0.5%, consider it dry. If the specimen was wet when its mass was first determined, place it in the oven for a second drying treatment of 24 hours and again determine the mass. In case of any doubt, redry the specimen for 24 hour periods until check values of mass are obtained. If the difference between values obtained from two successive values of mass exceeds 0.5% of the lesser value, return the specimens to the oven for an additional 24 hour drying period, and repeat the procedure until the difference between any two successive values is less that 0.5 % of the lowest value obtained. Designate this last value **A**.

5.2. Immerse the specimen on its edge in water at 72 ± 5°F (22 ±3°C). Do not place the specimen on the flat surface of the cylinder. Continue soaking the specimen in water for not less than 48 hours and until two successive values of mass of the surface-dried sample at intervals of 24 hours show an increase in mass of less than 0.5% of the larger value. Surface-dry the specimen by removing surface moisture with a towel, and determine the mass. Designate the final surface-dry mass after immersion **B**.

5.3. Begin boiling tap water in a suitable container. Verify that the water is rapidly boiling prior to placing the specimens in the water for testing. Place the specimen on its edge on a rack in the boiling water a minimum of 1/4" from the bottom of the container. The water must return to boiling in not less than 1 hour. Boil the specimen completely submersed for a minimum of 5 hours. Do not add additional water during boiling. Allow it to cool by natural loss of heat for not less than 14 hours to a final temperature of 72 ± 5°F (22 ± 3°C). Continue to store the samples on their edge in the boiled water until the final two steps are completed.

5.4. Suspend the specimen in the bucket at a constant water level by the suitable apparatus and determine the apparent mass of the sample in water at 77 ± 2 ° F (25 ± 1 °C). Designate this apparent mass **D**.

5.5. Remove the sample from the water. Quickly damp dry the sample with a damp absorbent cloth and determine the mass of the specimen. Designate the soaked, boiled, surface-dried mass **C**.

6. CALCULATION Page 3/3 5.9.73 04-12 KT-73

6.1. By using the values for mass determined in accordance with the procedures described in **Section 5** of this test method make the following calculations:

Absorption after immersion, % = $[(B-A)/A] \times 100$

Absorption after immersion and boiling, % = $[(C-A)/A] \times 100$

Bulk density, dry = $[A/(C-D)]\cdot\rho = g1$

Bulk density after immersion = $[B/(C-D)]\cdot\rho$

Bulk density after immersion and boiling = $[C/(C-D)]\cdot\rho$

Apparent density = $[A/(A-D)]\cdot\rho = g2$

Volume of permeable pore space (voids), % = $(g2-g1)/g2 \times 100$ or $[(C-A)/(C-D)] \times 100$

Where: A = Mass of oven dried sample in air
B = Mass of surface-dry sample in air after immersion
C = Mass of surface-dry sample in air after immersion and boiling
D = Apparent mass of sample in water after immersion and boiling
g1 = Bulk density, dry
g2 = Apparent density
ρ = Density of water

Appendix C: Round Robin Mix Designs

Mix #1						
Round Robin Test		**Design Strength 4500 psi**		**W/C ratio 0.44**	**Slump 3" +/- 1.00**	
Material Type	**Material**			**Design Qty (yd3)**	**Sp. Gr.**	**Volume ft3**
Cement	Type I/II Ash Grove Chanute			602 lb	3.150	3.06
Stone	KDOT SCA-3 Hunt Martin Materials Stamper			1573	2.640	9.54
Sand	C-33-Holiday Sand & Gravel, Riverside			1573	2.630	9.58
Water	WATER			267.0 lb	1.000	4.28
Air Volume						0.54

Mix #2						
RMXVJ40LBBB		**Design Strength 4500 psi**		**W/C ratio 0.45-**	**Slump 4" +/- 1.00**	
Material Type	**Material**			**Design Qty (yd3)**	**Sp. Gr.**	**Volume ft3**
Cement	Monarch Type I/II Cement-RIAB1			521 lb		2.65
Sand	Lafarge Agg MA-Sand AG2183			1997 lb		12.21
Stone	Martin Marietta ASTM 57/AG1097			1075 lb		6.67
Water	City water RIW00			234 lb		3.76
Air Volume	AIR			6.50%		1.75
AEA	WR Grace Daravair AT60-RIE20			0.63 foz.		
Mid Range WR	WR Grace Daracem 55- RIDBI			4.00 foz.		0.02

Slump +/- 1.0 Air 6.5 +/-1.5%

Mix #3						
4000# 60/20/20		**Design Strength 4000 psi**		**W/C ratio 0.49**	**Slump 4" +/- 1.00**	
Material Type	**Material**			**Design Qty (SSD)**		**Volume ft3**
Cement	ASHGROVE TYPE I/II CEMENT			560.0 lb		2.9
Fine Aggregate	MCM FINE AGGREGATE			1865.0 lb		11.4
Coarse Aggregate	BAYER MQ ASTM 57/67-CA4			624.0 lb		3.8
Coarse Aggregate	MCM RP CA-4			610.0 lb		3.8
Water	WATER			32.9 gal		4.4
	Air Content			3.00%		0.8

Slump +/- 1.0 Air% +/- 1.5

Mix #4						
RMXK140LE63		**Design Strength 4000 psi**		**W/C ratio 0.48-**	**Slump 2" +/- 1.00**	
Material Type	**Material**			**Design Qty (yd3)**	**Sp. Gr.**	**Volume ft3**
Cement	Lafarage Cement-01 Type I/II Cement RIABI			313 lb		1.59
Cement	Lafarage Cement-01 Flyash Type C-RIB10			52 lb		0.32
Cement	Lafarage Cement-01 Slag RIB90			156 lb		0.86
Sand	Hoilday Sand-20 Concrete San AG7484			1424 lb		8.67
Stone	Hunt Martin-11 KDOT CL1 CA4, 5,6-AG7000			1606 lb		9.89
Water	City water RIW00			250 lb		4.01
Air Volume	AIR			6.00%		1.62
AEA	WR Grace Daravair AT60-RIE20			3.13 foz.		
Mid Range WR	WR Grace Daracem 55- RIDBI			26.05 foz.		0.03

Slump +/- 1.0 Air 6.5 +/-1.5%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