

**Appendix 2: KDOT Physical Tests & Other Laboratory Procedures**

## **KDOT Physical Test Procedures and Calculations**

Guidelines presented below are reproduced from two sources. Information about ASTM testing is from the Annual Book of ASTM Standards (ASTM, 1995) and information pertaining to KDOT test methods is from the 1990 edition of the Standard Specifications for State Road and Bridge Construction, (Kansas Department of Transportation, 1990).

### **KDOT Modified Soundness Test for Aggregates**

#### ***Description***

This test, known as the “Modified Freeze and Thaw” test, shall be used to determine the soundness characteristics of Durability Classed Aggregate (Class 0 and 1).

#### ***Sample Preparation***

Preliminary preparation shall include removal of all material retained on the 3/4 “ mesh sieve and that passing the 3/8” mesh sieve, and the removal of all mud, clay lumps or sticks. The material shall not be washed. Shale and shale-like material, coal, asphalt coated pieces, rotten stone, soft or friable particles and other foreign material shall not be removed prior to testing. The material shall then be oven dried to a constant mass at a temperature of  $230 \pm 9^{\circ}$  F. Final preparation shall consist of screening oven dried material over 3/4:, 1/2” and 3/8” mesh sieves to meet the following grading.

<u>Individual Sieves</u>	<u>Cumulative Weight Retained (gms)</u>
3/4”	0
1/2”	2,500
3/8”	5,000

### ***Procedure***

After sieving, the material shall be placed in an open top container, covered with a No. 16 mesh sieve cloth and submerged in tap water maintained at a temperature from 70° to 80° F for a period of  $24 \pm 4$  hours. The sample shall then be tested in accordance with subarticle 1117(s)(4.2) and (4.3). One freezing period and one thawing period shall be considered one cycle. After the sample has been subjected to 25 cycles of freezing and thawing it shall be washed over a No. 12 sieve and oven dried to a constant mass at a temperature of  $230^{\circ} \text{ F} \pm 9^{\circ} \text{ F}$ . The sample shall then be screened over a 1/2" and 3/8" mesh sieve.

### ***Calculation***

(1)The cumulative percentage of material retained on each sieve (3/4", 3/8", No. 4 and No. 8) before testing shall be computed and recorded. (2) The cumulative percentage of material retained on each sieve at the end of the test shall be computed and recorded.(3) The sum of the cumulative percentages of aggregate retained son the sieves after 25 cycles of freezing and thawing shall be divided by the sum of the cumulative percentages of aggregates retained on the same screens before testing. The value obtained shall be known as the freeze-thaw loss ratio.

## **[KDOT Determination of Specific Gravity and Absorption](#)**

### ***Description***

This test method covers the procedures for determining the specific gravity and absorption of Durability Classed Aggregates.

### ***Sample Preparation***

Select a portion of the aggregate by splitting or quartering. The minimum weight of the sample, all of which passes the 3/4" sieve and is retained on the 3/8" sieve, shall be separated as shown below.

<u>Individual Sieve Size</u>	<u>Weight (grams)</u>
Passing 3/4" and retained on 1/2"	2800
Passing 1/2" and retained on 3/8"	2800

Thoroughly wash the sample over the No. 12 sieve to remove dust and other adherent coating.

Dry the sample to a constant weight in the oven. Combine the two fractions to provide a sample meeting the following guidelines.

<u>Sieve Size</u>	<u>Cumulative Weight Retained (grams)</u>
	0
3/4"	2250
1/2"	4500
3/8"	

### ***Procedure***

Immerse the sample in water and stir vigorously. Soak for a period of  $24 \pm 4$  hours. Remove the sample from the water and bring it to a dampened absorbent cloth. For the purpose of this test, saturates surface-dry condition of the aggregate has been reached when the particle surface appears to be moist but not shiny.

Weigh the sample immediately after obtaining the saturated surface-dry condition. All weights used in this test shall be to the nearest one gram. Immediately after obtaining the saturated surface-dry weight, immerse in water, stir to remove any entrapped air and weigh. The

water temperature shall be  $75^{\circ} \pm 10^{\circ}$  F. Dry the sample at a constant weight at a temperature of approximately  $230^{\circ}$  F. Cool the sample to room temperature and weigh.

### ***Calculation***

(1) Bulk Specific Gravity =  $A/(B-C)$

(2) Bulk Specific Gravity: Saturated Surface-Dry Basis =  $B/(B-C)$

(3) Apparent Specific Gravity =  $A/(A-C)$

(4) Absorption (%) =  $100 \times [(B-A)/A]$

Where: A = Weight in grams of oven-dry sample in air

B = Weight in grams of saturated surface-dry sample in air

C = Weight in grams of saturated sample in water

## **ASTM C666: Standard Test Method for Resistance of Concrete to Rapid Freezing and Thawing: Procedure B**

### ***Scope***

This test method covers the determination of the resistance of concrete specimens to rapidly repeated cycles of freezing and thawing in the laboratory. The procedure is intended for use in determining the effects of variation in the properties of concrete on the resistance of the concrete to the freezing-and-thawing cycles.

### ***Significance and Use***

As noted in the scope, the procedure described in this test method is intended to determine the effects of variations in both properties and conditioning of concrete in the resistance to freezing and thawing cycles. Specific applications include the ranking of coarse aggregates as to their effect on concrete freeze-thaw durability, especially where soundness of the aggregate is questionable.

It is assumed that the procedures will have no significantly damaging effects on frost-resistant concrete which may be defined as (1) any concrete not critically saturated with water (that is, not sufficiently saturated to be damaged by freezing) and (2) concrete made with frost-resistant aggregates and having an adequate air-void system that has achieved appropriate maturity and thus will prevent critical saturation by water under common conditions.

If as a result of performance tests as described in this test method concrete is found to be relatively unaffected, it can be assumed that it was either not critically saturated, or was made with “sound” aggregates, a proper air-void system, and allowed to mature properly.

### ***Apparatus***

The freezing-and-thawing apparatus shall consist of a suitable chamber or chambers in which the specimens may be subjected to the specified freezing and thawing cycle, together with the necessary refrigerating and heating equipment and controls to produce continuously, and automatically, reproducible cycles within the specified temperature requirements.

The apparatus shall be arranged so that, except for necessary supports, each specimen is completely surrounded by air during the freezing phase of the cycle and by water during the thawing phase. Rigid containers which have the potential to damage specimens, are not permitted.

### ***Freezing-and-Thawing Cycle***

Conformity with the requirement for the freezing-and-thawing cycle temperature measurements are based on measurements of control specimens of similar concrete in which suitable temperature-measuring devices are embedded.

The nominal freezing-and-thawing cycle shall consist of alternately lowering the temperature of the specimens from 40 to 0° F and raising it to 40° F in not less than 2 nor more

that 5 hours. Not less than 20% of the time shall be used for thawing. At the end of the cooling period the temperature at the centers of the specimens shall be  $0^{\circ} \pm 3^{\circ}$  F, and at the end of the heating period the temperature shall be  $40^{\circ} \pm 3^{\circ}$  F with no specimen at any time reaching a temperature lower than  $-3^{\circ}$  F nor higher than  $43^{\circ}$  F. The time required for the temperature at the center of any single specimen to be reduced from  $37$  to  $3^{\circ}$  F shall be not less than one half of the length of the cooling period, and the time required for the temperature at the center of any single specimen to be raised from  $3$  to  $37^{\circ}$  F shall not be less than one half of the length of the heating period. For specimens to be compared to each other, the time required to change the temperature at the centers from  $35$  to  $10^{\circ}$  F shall not differ by more than one sixth of the length of the cooling period for any single specimen and the time required to change the temperature at the centers of any specimens from  $10$  to  $35^{\circ}$  F shall not differ by more than one third of the length of the heating period for any single specimen.

The difference between the temperature at the center of a specimen and the temperature at its surface shall at no time exceed  $50^{\circ}$  F. The period of transition between freezing and thawing phases of the cycle shall not exceed 10 minutes.

### ***Procedure***

Immediately after the specified curing period bring the specimen to a temperature within  $-2^{\circ}$ F and  $+4^{\circ}$ F of the target thaw temperature that will be used in the freeze-thaw cycle and test for fundamental transverse frequency, weigh, determine the average length and cross section dimensions of the concrete specimen and determine the initial length comparator(optional) with the length change comparator. Protect the specimens against loss of moisture between the time of removal from curing and the start of the freezing-and-thawing cycles.

Start freezing-and-thawing test by placing the specimens in the thawing water at the beginning of the thawing phase cycle. Remove the specimens from the apparatus, in a thawed condition, at intervals not exceeding 36 cycles of exposure to the freezing-and-thawing cycles, test for fundamental transverse frequency and measure length change (optional) with the specimens within the temperature range, weigh each specimen, and return them to the apparatus. To ensure that the specimens are completely thawed and at the specified temperature place them in a tempering tank or hold them at the end of the thaw cycle in the freezing-and-thawing apparatus for a sufficient time for this condition to be attained throughout each specimen to be tested. Protect the specimens against loss of moisture while out of the apparatus and turn them end-for-end when returned. Return the specimens either to random positions in the apparatus or to positions according to some predetermined rotation scheme that will ensure that each specimen that continues under test for any length of time is subjected to conditions in all parts of the freezing apparatus.

Continue each specimen in the test until it has been subjected to 300 cycles of freezing-and-thawing or until its relative dynamic modulus of elasticity reaches 60% of the initial modulus, whichever comes first, unless other limits are specified. For the optional length change test, 0.10% expansion may be used as the end of test. Whenever a specimen is removed because of failure, replace it for the remainder of the test with a dummy specimen.

Each time the specimen is tested for fundamental frequency and length change make a note of visual appearance and make special comment on any defects that develop. When it is anticipated that specimens may deteriorate rapidly, they should be tested for fundamental transverse frequency and length change (optional) at intervals not exceeding 10 cycles when initially subjected to freezing and thawing.

When the sequence of freezing and thawing must be interrupted store specimens in a frozen condition.

### ***Calculation***

*Relative Dynamic Modulus of Elasticity* - Calculate the numerical values of relative dynamic modulus of elasticity as follows:

$$P_c = (n_1^2/n^2) \times 100$$

Where:  $P_c$  = relative dynamic modulus of elasticity, after  $c$  cycles of freezing and thawing, percent

$n$  = fundamental transverse frequency at 0 cycles of freeze-thaw

$n_1$  = fundamental transverse frequency after  $c$  cycles of freeze-thaw

*Durability Factor* - Calculate the durability factor as follows:

$$DF = PN/M$$

Where: DF = durability factor of the tested specimen

P = relative dynamic modulus of elasticity at N cycles, percent

N = number of cycles at which P reaches a specified minimum value for discontinuing the test or the specified number of cycles at which the exposure is to be terminated, whichever is less

M = specified number of cycles at which the exposure is to be terminated

*Length Change in Percent (Expansion)* - Calculate the length change as follows:

$$L_C = \frac{(l_2 - l_1)}{L_g} \times 100$$

Where:  $L_C$  = length change of the test specimen after C cycles of freeze-thaw, %

$l_1$  = length comparator reading at 0 cycles

$l_2$  = length comparator reading after C cycles

$L_g$  = the effective gage between the innermost ends of the gage studs

## **ASTM C131: Standard Test Method for Resistance to Degradation of Small-Size Coarse Aggregate by Abrasion and Impact in the Los Angeles Machine**

### ***Scope***

This test method covers a procedure for testing sizes of coarse aggregate smaller than 1 1/2" for resistance to degradation using the Los Angeles testing machine.

### ***Summary of Test Method***

The Los Angeles test is a measure of degradation of mineral aggregates of standard gradings resulting from a combination of actions including abrasion or attrition, impact, and grinding in a rotating steel drum containing a specified number of steel spheres, the number depending upon the grading of the test sample. As the drum rotates, a shelf plate picks up the sample and the steel spheres, carrying them around until they are dropped to the opposite side of the drum, creating an impact-crushing effect. The contents then roll within the drum with an abrading and grinding action until the shelf plate impacts and the cycle is repeated. After the prescribed number of revolutions, the contents are removed from the drum and the aggregates portion is sieved to measure the degradation as percent loss.

### ***Significance and Use***

The Los Angeles test has been widely used as an indicator of the relative quality or competence of various sources of aggregate having similar mineral compositions. The results do not automatically permit valid comparisons to be made between sources distinctly different in origin, composition or structure. Specification limits based on this test should be assigned with extreme care in consideration of available aggregate types and their performance history in specific end uses.

### ***Procedure***

Place the test sample and the charge in the Los Angeles testing machine and rotate the machine at a speed of 30 to 33 rpm for 500 revolutions, discharge the material from the machine and make a preliminary separation of the sample on a sieve coarser than the 1.70 mm (No. 12). Wash the material coarser than the 1.70 mm sieve, oven dry at 221 to 230°F to substantially constant weight and weigh to the nearest 1 gram.

### ***Calculation***

Express the loss (difference between the original weight and the final weight of the test sample) as a percentage of the original weight of the test sample. Report this value as the percent lost.

*The following tests and procedures were performed by the author, using laboratory equipment provided by the University of Kansas Department of Geology.*

### **Determination of Percent Insoluble Residue**

1. Obtain crushed aggregate sample and split into two fractions (one of 3/8 inch and one of 1/2 inch aggregate) of 50 grams each. Dry in oven at approximately 150° overnight.
2. Digest in 10% hydrochloric acid (HCl) by placing in large beaker and adding acid in 100 ml increments until all reaction ceases. Allow to sit for several hours to ensure reaction is complete.
3. Filter residue and solution through filter paper capable of retaining clay size particles.
4. Remove residue from filter as completely as possible. (Save filters)
5. Allow sample to dry at room temperature for 48-72 hours or place in oven at approximately 90 degrees C for 4-5 hours.
6. Weigh samples and record weights.
7. Weigh filter papers with remaining residues and record. Also weigh several empty, dry filter papers and average weight to subtract as standard.
8. Store samples in airtight, labeled vials for later use.
9. Calculate percentage of original 100 gram sample that is insoluble residue

### **Sample Preparation of Insoluble Residues for X-Ray Diffraction Study**

1. Place approximately 1 gram of insoluble residue in plastic test tube. Also place equal amount of Calgon (commercial soap that contains sodium hexametaphosphate) in tube for dispersion.

2. Add 7-10 ml of water to tube and agitate in mechanical shaker for 10 minutes to separate clays from coarser particles.
3. After dispersion is accomplished, immediately centrifuge sample for 4-5 minutes to accomplish particle size separation.
4. Decant liquid into new tubes making sure to keep careful track of which tubes correspond to original sample and decanted sample. Save silt and sand sized fraction and keep wet by adding 5 ml of water to tube. The decanted fraction obtained in this step contains the clay size sediment fraction for x-ray identification.
5. Centrifuge clay sample for additional 15 minutes to settle out coarsest clay particles.
6. Using an eye-dropper, apply a small sample of the clay slurry to a ceramic tile cut to fit into sample holder of x-ray diffractometer.
7. Allow tile to dry so that clay is still damp but not dry enough to crack or peel.
8. Run x-ray diffractogram while sample is still damp.
9. Index and identify component minerals from resultant diffractogram.
10. From silt and sand sized slurry obtained from step 4, make a new ceramic tile with coarser fraction of sediment and run additional x-ray pattern to facilitate additional identifications.

### **Preparation of Aggregate Thin Sections for Petrographic Examination**

1. Obtain enough small cardboard boxes to hold one of each sample. Those boxes used in this study were 3 inch by 2 inch sample boxes.
2. Fill the sample boxes with equal amounts of washed and oven dried, 1/2 inch and 3/8 inch aggregate.

3. Pour clear modeling resin over aggregates to fill empty space and bond the aggregates together for cutting. Allow to dry according to instructions for the resin.
4. Using a suitable rock saw, cut the base from the boxes to provide a smooth surface for thin section preparation.
5. Polish the bottom surface on a rotating polishing wheel so that it is flat and will evenly adhere to a glass slide.
6. Mount the aggregate box to a glass slide and prepare as a normal thin section.

### **Insoluble Residue Grain Size Separations**

1. Dry insoluble residue sample or a fraction thereof in oven at approximately 150° F overnight.
2. Weigh samples to the nearest .05 gram and record the weights as the original weight.
3. Place sample into large jar or bottle that can be tightly sealed. To the sample add approximately 1-2 grams of Calgon (commercial soap containing sodium hexametaphosphate) and approximately 100-150 ml of water.
4. Agitate bottle or jar by hand or using a mechanical shaker for a minimum of 5 minutes.
5. Wash the residue through stacked sieves of 500 microns, 250 microns, 125 microns and 63 microns to achieve grain size separations.
6. Place the sieves with the residues into an oven at approximately 125° F for 10-15 minutes.
7. Carefully remove all residues from each sieve being as quantitative as possible and weigh. Record each weight as a mass retained on each sieve. For example: Retained on 125 micron sieve = 1.25 grams.

8. Total the masses retained on each sieve. The difference between the original mass and the total of each fraction is the portion of the sample finer than 63 microns (finer than silt-sized sediment).

Lab. #/Sample #	Durability Factor	Modified Freeze/Thaw	Absorption %	Expansion %	LA Wear	% AIR
97-3685/KU-1	NC	81	3.53	0.14	30	11.22
97-3686/KU-2	94	95	2.78	0.02	29	4.22
97-3687/KU-3	97	87	3.76	0.013	41	13.32
97-3688/KU-4	98	94	1.58	0.013	24	9.22
97-3689/KU-5	99	91	2.08	0.011	29	3.72
97-3690/KU-6	96	94	1.53	0.015	28	2.32
97-3858/KU-7	96	77	2.18	0.013	27	8.87
97-4058/KU-8	97	94	3.76	0.015	34	5.37
97-4059/KU-9	99	93	2.47	0.005	31	3.02
97-4060/KU-10	82	94	2.04	0.064	25	6.47

**Table A2.1.** Results of KDOT physical testing for samples KU-1-10. See Appendix 2 for procedures and calculations. (% AIR = Percent Acid-Insoluble Residue; NC = Not Calculated)

Lab. #/Sample #	Durability Factor	Modified Freeze/Thaw	Absorption %	Expansion %	LA Wear	% AIR
95-0634/KDOT-1	98	95	1.18	0.007	24	3.10
95-634-P/KDOT-2	94	92	1.87	0.014	NC	5.30
93-4579/KDOT-3	78	87	1.69	0.05	27	2.89
93-4579/KDOT-4	86	87	1.52	0.038	24	2.59
94-0607/KDOT-5	82	90	3.72	0.048	41	14.69
94-0607/KDOT-6	80	97	4.67	0.076	35	2.75
94-2268/KDOT-7	99	96	1.67	0.005	23	1.06
94-2268/KDOT-8	99	97	2.16	0.004	28	1.60
94-2268/KDOT-9	98	95	1.90	0.014	29	9.99
94-2268/KDOT-10	94	94	1.20	0.026	25	3.64
94-2268/KDOT-11	NC	81	3.26	NC	31	8.70
93-4579/KDOT-12	NC	84	2.76	NC	30	7.91
95-634-P/KDOT-13	NC	75	3.73	NC	NC	9.48
81-0083/KDOT-14	33	89	2.76	0.122	NC	8.47
81-0083/KDOT-15	51	93	2.82	0.147	NC	7.85
81-0083/KDOT-16	94	92	2.44	0.031	NC	1.53
81-0083/KDOT-17	94	98	2.97	0.017	NC	2.86
97-2114/KDOT-18	96	92	1.39	0.025	25	1.64
97-2114/KDOT-19	94	96	1.71	0.022	27	3.54
97-2114/KDOT-20	NC	83	1.99	NC	28	1.84

**Table A2.2.** Results of KDOT physical testing for samples KDOT-1-20. See Appendix 2 for procedures and calculations. (% AIR = Percent Acid-Insoluble Residue; NC = Not Calculated)

Lab. #/Sample #	% >.5 mm	% .25 -.5 mm	% .12 - .25 mm	% .06 - .12 mm	% < .06 mm
97-3685/KU-1	3.33	3.80	4.51	2.38	85.99
97-3686/KU-2	0	6.38	5.11	4.26	84.25
97-3687/KU-3	0.50	1.06	17.02	32.98	48.4
97-3688/KU-4	0	0	4.4	15.38	80.22
97-3689/KU-5	0	0	4	14.4	81.6
97-3690/KU-6	0	0	9.09	6.06	84.85
97-3858/KU-7	0	0	3.26	6.09	90.65
97-4058/KU-8	8.33	6.25	4.16	9.17	72.08
97-4059/KU-9	0	0	0	0	100
97-4060/KU-10	0	0	0	10.32	89.68

**Table A2.3.** Grain-size distributions for insoluble residues of samples KU-1-10. Data is given as a percentage of the total residue that is composed of 5 grain size categories.

Lab. #/Sample #	Bulk Spar %	Avg. Crystal Size	Total Agg. Spar %
97-3685/KU-1	10.00	70	25
97-3686/KU-2	25.00	400	30
97-3687/KU-3	5.00	75	50
97-3688/KU-4	10.00	100	80
97-3689/KU-5	30.00	200	40
97-3690/KU-6	50.00	150	60
97-3858/KU-7	15.00	50	50
97-4058/KU-8	15.00	75	25
97-4059/KU-9	25.00	150	60
97-4060/KU-10	15.00	75	30
95-0634/KDOT-1	25.00	400	
95-634-P/KDOT-2	20.00	250	
93-4579/KDOT-3	20.00	250	
93-4579/KDOT-4	50.00	400	
94-0607/KDOT-5	15.00	75	
94-0607/KDOT-6	30.00	200	
94-2268/KDOT-7	25.00	150	
94-2268/KDOT-8	25.00	150	
94-2268/KDOT-9	25.00	75	
94-2268/KDOT-10	20.00	150	
94-2268/KDOT-11	15.00	75	
93-4579/KDOT-12	5.00	100	
95-634-P/KDOT-13	20.00	75	
81-0083/KDOT-14	15.00	100	
81-0083/KDOT-15	15.00	100	
81-0083/KDOT-16	30.00	200	
81-0083/KDOT-17	20.00	200	
97-2114/KDOT-18	30.00	400	
97-2114/KDOT-19	30.00	400	
97-2114/KDOT-20	30.00	250	

**Table A2.4.** Data concerning bulk spar percentage, average spar crystal size and aggregate spar percentage. See Chapter 3 for a definition of each category.

Lab. #/Sample #	Clay %	Dif./Diss. Clay %
97-3685/KU-1	75.00	65
97-3686/KU-2	55.00	50
97-3687/KU-3	2.00	2
97-3688/KU-4	2.00	2
97-3689/KU-5	15.00	5
97-3690/KU-6	5.00	3
97-3858/KU-7	2.00	2
97-4058/KU-8	15.00	5
97-4059/KU-9	5.00	3
97-4060/KU-10	60.00	60
95-0634/KDOT-1	40.00	40
95-634-P/KDOT-2	45.00	30
93-4579/KDOT-3	55.00	40
93-4579/KDOT-4	5.00	5
94-0607/KDOT-5	2.00	15
94-0607/KDOT-6	15.00	5
94-2268/KDOT-7	5.00	3
94-2268/KDOT-8	5.00	3
94-2268/KDOT-9	5.00	50
94-2268/KDOT-10	10.00	15
94-2268/KDOT-11	15.00	5
93-4579/KDOT-12	2.00	2
95-634-P/KDOT-13	60.00	55
81-0083/KDOT-14	100.00	100
81-0083/KDOT-15	75.00	100
81-0083/KDOT-16	10.00	40
81-0083/KDOT-17	10.00	10
97-2114/KDOT-18	15.00	3
97-2114/KDOT-19	15.00	3
97-2114/KDOT-20	15.00	30

**Table A2.5.** Data regarding total percentage of clay-rich strata (Total Clay %) and percentage of strata that contains diffuse and disseminated clay (Dif./Dissem. Clay %).