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Key Words:

Concrete Rubble

Saturation

Porosity

Retention:

Permanent

**MOISTURE CONTENT AND POROSITY
OF
CONCRETE RUBBLE
STUDY**

October 7, 2005

PREPARED BY:

Frank C. Sappington

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**Westinghouse Savannah River Company
Savannah River Site
Aiken, SC 29808**



SRNL
SAVANNAH RIVER NATIONAL LABORATORY

Prepared for the U.S. Department of Energy under Contract No. DE-AC09-96SR1850

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1.0 Introduction

Tritium contaminated concrete rubble from the 232-F Tritium Facility was disposed in the Slit 1 Trenches 1 and 2 in 1997. A Special Analysis (SA) has been performed to evaluate any impact this disposal may have on the groundwater. The SA assumed that the disposed concrete rubble was fully saturated at the time of disposal, however if the concrete was less than fully saturated, migration of tritium out of the concrete would be slower than under fully saturated conditions. Therefore if the concrete at disposal was less than fully saturated, the PA assumption of full saturation would be a conservative assumption. In order to evaluate whether the PA assumption resulted in a conservative analysis from the standpoint of the concrete saturation, concrete rubble samples were collected from various facilities being demolished at the Savannah River Site (SRS) and evaluated for in-field moisture content, absorbable moisture, and water exchangeable porosity.

2.0 Task Description

The purpose of this task was to collect concrete rubble samples from various demolished SRS facilities for the purpose of determining in-field moisture content, absorbable moisture, and water exchangeable porosity. Since moisture content testing for concrete rubble is not typical, existing ASTM Standards were reviewed for method and procedure development.

3.0 Sample Collection

In an attempt to collect samples representative of the 232-F Tritium Facility concrete, samples were collected from various demolished SRS facilities including buildings in A-Area, D-Area, and TNX (T-Area). Table 1 identifies the demolished building from which concrete rubble samples were collected. Also provided are the dates the facilities were constructed for comparison to that of building 232-F. Buildings 734-A and 701-1D were built in the same year as building 232-F.

Table 1. Facility Construction Dates

Area / Building	Date Constructed
232-F	1953
734-A	1953
701-1D	1953
675-T	1983

Loose samples from each building were collected from the reinforced concrete slabs, columns, and walls. Two sets of samples (i.e. small and large) were collected from each

of the 3 areas/buildings. The sample size was determined by field availability. A total of 8 samples collected from each of the areas/buildings were used in the testing (Table 2). Appendix A provides photographs of various samples used during testing. The procedures that were utilized for sampling are provided in Appendix B.

Table 2. Sample Description

Sample and Container ID	Sample Location and Type	Sample Size	Initial Test
A-01	734-A Wall	Large	Oven Dry
A-02	734-A Wall	Large	Oven Dry
A-03	734-A Wall	Large	Saturate
A-04	734-A Wall	Large	Saturate
A-05	734-A Wall	Small	Oven Dry
A-06	734-A Wall	Small	Oven Dry
A-07	734-A Wall	Small	Saturate
A-08	734-A Wall	Small	Saturate
D-01	701-1D Slab	Large	Oven Dry
D-02	701-1D Slab	Large	Oven Dry
D-03	701-1D Slab	Large	Saturate
D-04	701-1D Slab	Large	Saturate
D-05	701-1D Slab	Small	Oven Dry
D-06	701-1D Slab	Small	Oven Dry
D-07	701-1D Slab	Small	Saturate
D-08	675-T Column ¹	Small	Saturate
TNX-01	675-T Column	Large	Oven Dry
TNX-02	675-T Slab	Large	Oven Dry
TNX-03	675-T Column	Large	Saturate
TNX-04	675-T Slab	Large	Saturate
TNX-05	675-T Column	Small	Oven Dry
TNX-06	675-T Slab	Small	Oven Dry
TNX-07	675-T Column	Small	Saturate
TNX-08	675-T Slab	Small	Saturate

¹ Sample ID D-8 appears to have been a TNX Column Sample

4.0 Method

The samples were collected on November 11, 2004. The weather was overcast with occasional light rain. The samples were transported back to building 736-A, where they were placed on the ground exposed to the atmosphere in a similar fashion to which they were found. The samples were allowed to remain on the ground exposed to the atmosphere until November 16, 2004. The weather on November 16, 2004 was clear and sunny with a temperature of 46°F and a humidity of 65%. At that time the samples were brought into the lab, sorted, identified, numbered and weighed. The samples from each area were separated into 2 groups of two large and two small samples. After the initial

weighing, the first group of each sample set was immediately placed in the oven to begin drying and the second group was placed in the water bath to begin the saturation process (Table 2).

The first group of samples, which were immediately placed in the oven, was periodically removed from the oven and the dried mass of each sample was determined. This process was continued until a constant mass for each sample was obtained as determined by a small change in dried mass. A sample mass change of less than 0.1 % in a 24 +/- hour period was the criterion utilized to determine when constant mass was obtained. This was done to determine the in-field moisture content.

The second group of samples was immersed in distilled water for sufficient time to saturate the samples (i.e., essentially fill the pores with water). They were periodically removed from the water, the water dried from the surface of the sample, and the saturated mass determined. This process continued until the sample has been in contact with water long enough to satisfy most of the water absorption potential as determined by a small change in saturated mass. A sample mass change of less than 0.1 % in a 24 +/- hour period was the criterion utilized to determine when constant mass was obtained. The volume (concrete and pores) was determined by placing the sample in a water displacement apparatus and measuring the mass of water displacement. The water displacement apparatus was simply a container with a drain from which displaced water could be collected. Volumetric measurements were obtained at day 6/7 of the saturation process, when the change in saturated mass had slowed to a rate which would not affect the volumetric measurement. This was done to determine the saturated moisture content (i.e., water exchangeable porosity)

For each group of samples the time, required to obtain a constant mass, varied depending on the concrete type, specimen size, number of samples in the oven, and other factors, therefore the time to obtain a constant mass was determined by trial and error. However to ensure completion of the process the samples were allowed to dry or saturate for a period of 14 days.

Subsequently the entire process was reversed with the first group of oven dried samples being placed in the water bath and the second group of water saturated samples being placed in the oven. This was done as a check on the previous measurements and to determine if there was a hysteresis effect. The procedures that were utilized for testing are provided in Appendix B.

5.0 Results

The minimum, maximum and average volume of the samples is shown in Table 3. Table 4 provides the results of the final calculations for each sample's volume, in-field volumetric moisture content, absorbed volumetric moisture, and saturated volumetric moisture content (i.e. water exchangeable porosity). Table 5 provides an averaged

moisture content evaluation based on sample size, location, type, age (1953 vs. 1983), and whether the samples were initially oven dried or saturated. Appendix C provides all laboratory data collected during the testing and the associated calculations.

Samples from the large sample set had volumes varying from .9L to 1.6L with an average of 1.3L, and samples from the small sample set had volumes varying from 140 ml to 321 ml with an average of 215 ml. The in-field volumetric moisture content of the concrete samples ranged from 0.070 to 0.132 with an average of 0.096. The volumetric moisture that the samples absorbed ranged from 0.005 to 0.079 with an average of 0.036. This moisture absorption resulted in a final saturated volumetric moisture content (i.e. water exchangeable porosity) range of 0.083 to 0.178 with an average of 0.132. It appears that there might have been a slight hysteresis effect as seen by the differences between samples which were initially oven dried versus those that were initially saturated. Concrete samples which were initially oven dried had an average in-field volumetric moisture content, absorbed volumetric moisture, and saturated volumetric moisture content of 0.093, 0.034, and 0.127 respectively, whereas the samples which were initially saturated had values of 0.099, 0.038, and 0.136, respectively. The values for samples which were initially saturated were slightly greater than those which were initially oven dried. However the difference is relatively small. Based upon sample location and type, sample size, and year the concrete was poured, differences in the average in-field volumetric moisture contents, absorbed volumetric moistures, and saturated volumetric moisture contents are presented in the Table 5. However, the primary differences are seen between the difference sample locations (i.e. buildings 734-A, 701-1D, and 675-T), which probably relates to the concrete mix and curing condition of the concrete utilized at each location. The concrete samples from building 734-A have the lowest average in-field volumetric moisture contents, absorbed volumetric moistures, and saturated volumetric moisture contents. Whereas, the values for these parameters from concrete samples from 701-1D and 675-T are very similar. All concrete samples tested had in-field moisture contents less than saturation and were capable of absorbing further moisture.

Table 3. Average Sample Volumes

	Large (ml)	Small (ml)
Minimum	943	141
Maximum	1590	321
Average	1256	215

Table 4. Sample Volume and Moisture Contents

Sample ID	Sample Location and Type	Sample Volume (mL)	In-field Volumetric Moisture Content	Absorbed Volumetric Moisture	Saturated Volumetric Moisture Content ²
A-01	734-A Wall	1580.32	0.071	0.012	0.083
A-02	734-A Wall	1464.82	0.082	0.005	0.087
A-03	734-A Wall	1107.59	0.080	0.015	0.096
A-04	734-A Wall	1589.51	0.073	0.017	0.090
A-05	734-A Wall	181.14	0.080	0.013	0.093
A-06	734-A Wall	320.72	0.070	0.016	0.086
A-07	734-A Wall	141.11	0.080	0.020	0.100
A-08	734-A Wall	174.56	0.093	0.015	0.108
D-01	701-1D Slab	1002.21	0.109	0.021	0.130
D-02	701-1D Slab	1442.74	0.128	0.026	0.154
D-03	701-1D Slab	1055.51	0.124	0.030	0.154
D-04	701-1D Slab	1134.56	0.132	0.042	0.174
D-05	701-1D Slab	228.65	0.100	0.044	0.144
D-06	701-1D Slab	228.30	0.121	0.046	0.167
D-07	701-1D Slab	216.28	0.076	0.048	0.124
D-08	675-T Column ¹	188.93	0.109	0.049	0.159
TNX-01	675-T Column	1411.52	0.108	0.049	0.157
TNX-02	675-T Slab	1241.33	0.083	0.044	0.127
TNX-03	675-T Column	1102.18	0.104	0.055	0.159
TNX-04	675-T Slab	942.95	0.100	0.042	0.141
TNX-05	675-T Column	175.53	0.083	0.079	0.162
TNX-06	675-T Slab	223.46	0.084	0.049	0.133
TNX-07	675-T Column	246.35	0.108	0.071	0.178
TNX-08	675-T Slab	255.15	0.104	0.049	0.154

Notes to Table 4:

¹ Sample ID D-8 appears to be a TNX Column Sample

² Water exchangeable porosity

	Initially oven dried then saturated
	Initially saturated then oven dried

Table 5. Average Moisture Content Evaluation

Sample Size	Sample Location and Type	In-field Volumetric Moisture Content	Absorbed Volumetric Moisture	Saturated Volumetric Moisture Content
Large And Small	734-A Wall	0.079	0.014	0.093
Large And Small	701-1D Slab	0.113	0.036	0.150
Large And Small	675-T Column & Slab	0.098	0.054	0.152
Large Only	734-A Wall	0.077	0.012	0.089
Large Only	701-1D Slab	0.123	0.030	0.153
Large Only	675-T Column & Slab	0.099	0.048	0.146
Large Only	Average	0.100	0.030	0.129
Small Only	734-A Wall	0.081	0.016	0.097
Small Only	701-1D Slab	0.099	0.046	0.145
Small Only	675-T Column & Slab	0.098	0.059	0.157
Small Only	Average	0.093	0.040	0.133
Large And Small	734-A Wall	0.079	0.014	0.093
Large Only	734-A Wall	0.077	0.012	0.089
Small Only	734-A Wall	0.081	0.016	0.097
Large And Small	701-1D Slab	0.113	0.036	0.150
Large Only	701-1D Slab	0.123	0.030	0.153
Small Only	701-1D Slab	0.099	0.046	0.145
Large And Small	675-T Column & Slab	0.098	0.054	0.152
Large Only	675-T Column & Slab	0.099	0.048	0.146
Small Only	675-T Column & Slab	0.098	0.059	0.157
Large And Small	675-T Slab	0.093	0.046	0.139
Large And Small	675-T Column	0.102	0.061	0.163
1953	734-A Wall & 701-1D Slab	0.096	0.026	0.122
1983	675-T Column & Slab	0.098	0.054	0.152
Oven Dried	All Initially Oven Dried	0.093	0.034	0.127
Saturated	All Initially Saturated	0.099	0.038	0.136
Overall Average	All Samples	0.096	0.036	0.132

6.0 Conclusions

All concrete samples tested had in-field moisture contents less than saturation and were therefore capable of absorbing further moisture. The in-field volumetric moisture content averaged 0.096, the volumetric moisture that the samples absorbed averaged 0.036, and the total water exchangeable porosity averaged 0.132. The difference seen in in-field volumetric moisture content, amount of moisture that could be absorbed, and total water exchangeable porosity was probably related to the concrete mix and curing condition of the concrete utilized at each location.

7.0 References

ASTM C 127 – 04, Standard Test Method for Density, Relative Density (Specific Gravity), and Absorption of Coarse Aggregate
ASTM C 566-97 (Reapproved 2004), Standard Test Method for Total Evaporable Moisture Content of Aggregate by Drying
ASTM D 2216 – 98, Standard Test Method for Laboratory Determination of Water (Moisture) Content of Soil and Rock by Mass

8.0 Appendices

The following appendices are provided:

- Appendix A, Sample Photographs
- Appendix B, Sampling and Testing Procedures
- Appendix C, Lab Data and Calculations

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Appendix A

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APPENDIX A
SAMPLE PHOTOGRAPHS



Figure 1 Sample ID (A-1 Wall)



Figure 2 Sample ID (D-1 Slab)



Figure 3 Sample ID (D-5 Slab)



Figure 4 Sample ID (TNX-1 Column)



Figure 5 Sample ID (TNX-2 Slab)



Figure 6 Sample ID (TNX-6 Slab)

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Appendix B

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**APPENDIX B
SAMPLING AND TESTING PROCEDURES**

FIELD SAMPLING PROCEDURE

1.0 Scope

1.1 This procedure covers the collection of samples in the field.

2.0 Samples

2.1 Loose samples, from reinforced concrete slabs and or walls, will be obtained from 2-3 locations on the Savannah River Site (SRS). Those areas from which samples may be collected are A, D, and TNX. Samples will be collected for the purpose of determining existing and saturated moisture content.

2.2 Two sets of samples (i.e. small and large) will be collected from each of the 2-3 areas. Samples from the large sample set will have the approximate volume of 1 liter (61 in³) and samples from the small sample set will have the approximate volume of 100 ml (6 in³). Final size of the sample will be determined by field availability. Each of the two sample sets from each of the 2-3 areas will consist of four samples. A total of 8 samples will be collected from each of the areas.

2.3 Keep the samples that are stored prior to testing in noncorrodible airtight containers at a temperature between approximately 3 and 30°C and in an area that prevents direct contact with sunlight. Samples shall be stored in such a way as to prevent or minimize moisture condensation on the insides of the containers.

2.34 The water content determination should be done as soon as practicable.

3.0 Procedure

3.1 Collect samples.

3.2 Mark both samples and sample bags with an indelible marker and place sample in sample bag. There shall be one sample per bag.

3.3 Transport samples back to the lab and begin Moisture Content and Volume Determination Procedures as soon as practicable.

TOTAL EVAPORABLE MOISTURE CONTENT PROCEDURE

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1. Scope

1.1 This test method covers the determination of the percentage of as-is evaporable moisture in a sample by removing/driving off both surface moisture and moisture in the pores.

2. Significance and Use

2.1 Large samples will require greater time for the moisture to travel from the interior of the particle to the surface. The user of this test method should determine by trial when samples are fully dry.

2.2 Since some dry materials may absorb moisture from moist specimens, dried specimens should be removed before placing moist specimens in the same oven.

2.3 The as-is sample mass will be determined initially by oven drying. Subsequently, the sample is immersed in distilled water for sufficient time to essentially fill the pores. It is then removed from the water, the water dried from the surface of the sample, and the mass (saturated) determined. When it is deemed that the sample has been in contact with water long enough to satisfy most of the absorption potential, the volume (concrete and pores) shall be determined using a displacement apparatus and the displacement of water method.

3. Apparatus

3.1 *Balance*—A balance or scale accurate, readable, and sensitive to within 0.1 % of the test load at any point within the range of use. Within any interval equal to 10 % of the capacity of the balance or scale used to determine mass, the load indication shall be accurate within 0.1 % of the difference in masses.

3.2 *Source of Heat*—A ventilated oven capable of maintaining the temperature surrounding the sample at 110 +/- 5°C (230 +/- 9°F).

3.3 *Water Displacement Apparatus* -A device used to determine the volume of displacement of a sample in water. The container will have a drain from which the displaced water will be collected. The weight of water will be determined. The weight will be converted to volume with the density of water at the temperature of the water.

3.4 *Thermometer* –With divisions of 1° C or 2°F.

4. Samples

4.1 Four samples collected from each of the 2-3 areas as outlined in the field sampling procedure will be tested.

4.2 Keep the samples that are stored prior to testing in noncorrodible airtight containers at a temperature between approximately 3 and 30°C and in an area that prevents direct contact with sunlight. Samples shall be stored in such a way as to prevent or minimize moisture condensation on the insides of the containers.

4.3 The water content determination should be done as soon as practicable after sampling.

4.4 For each measurement taken the values, including time and date shall be recorded.

5. Procedure

Note: Drying-Metal containers shall be used during oven drying of the samples. The container and lid shall be clearly marked or scribed with the sample or other reference number. If multiple samples are dried in the oven at the same time a layout diagram will be used in case the sample ID's are lost (baked off). The time required to obtain constant mass will vary depending on the type of material, size of specimen, oven type and capacity, and other factors.

5.1 Determine the individual mass of the sample and the mass of the container and lid to the nearest 0.1 %. Record all values.

5.2 Place sample in container (without lid) and dry the sample thoroughly. The sample is thoroughly dry when further heating causes, or would cause, less than 0.1 % additional loss in mass. Measurements shall be made at 24 hour +/- increments. Drying should be continued until the change in mass after two successive periods of drying is an insignificant amount (less than about 0.1 % of the mass of the sample). The samples shall be stored in containers with tight fitting lids if it appears that the specimen is absorbing moisture from the air prior to determination of its dry mass. Cooling in a desiccator is acceptable in place of containers with tight fitting lids since it greatly reduces absorption of moisture from the atmosphere during cooling.

5.3 After the material has dried to constant mass, remove the container/sample from the oven and replace the lid. Allow the material and container to cool to room temperature or until the container can be handled comfortably with bare hands and the operation of the balance will not be affected by convection currents and/or its being heated. Determine the mass of the dried sample and container to the nearest 0.1 %. Weigh and record all values.

5.4 After mass of the dried sample has been determined immerse the sample in water at room temperature until the change in mass after two successive periods is an insignificant amount (less than about 0.1 % of the mass of the sample).

5.5 Remove the test sample from the water and wipe it in a large absorbent cloth until all visible films of water are removed. A moving stream of air is permitted to assist in the drying operation. Take care to avoid evaporation of water from sample pores during the surface-drying operation. Determine the mass of the test sample in the saturated surface-dry condition to the nearest 0.1 %. Record all values.

5.6 After determining the saturated-surface-dry (SSD) mass in air, immediately place the SSD sample in the water displacement apparatus that has been prepared to measure the displacement of water. Care shall be taken to remove entrapped air from the exterior of the sample. Record the temperature of water to yield the SSD sample volume. Record mass of displaced water and convert to a volume based upon the density of water at the temperature of the water. The volume will be determined twice.

References

ASTM C 566-97 (Reapproved 2004), Standard Test Method For Total Evaporable Moisture Content Of Aggregate By Drying
ASTM D 2216 – 98, Standard Test Method For Laboratory Determination Of Water (Moisture) Content Of Soil And Rock By Mass

AS SAMPLED AND TOTAL EXCHANGEABLE WATER FILLED PORE VOLUME DETERMINATION PROCEDURE

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1. Scope

1.1 This test method covers the determination of the “As Sampled and Total Exchangeable Water Filled Pore Volume Determinations”.

2. Definitions

2.1 *absorption*,—the increase in mass of sample due to water penetration into the pores of the sample during a prescribed period of time (but not including water adhering to the outside surface of the sample), expressed as a percentage of the dry sample mass.

2.2 *saturated-surface-dry (SSD)*,—the condition in which the permeable pores of sample are filled with water to the extent achieved by submerging in water, but without free water on the surface of the sample.

2.3 *density*,—the mass per unit volume of a material, expressed as kilograms per cubic meter (pounds per cubic foot).

2.4 *density (SSD)*,—the mass of saturated-surface-dry sample per unit volume of the sample, including the volume of impermeable pores and water-filled voids within the sample.

3. Significance and Use

3.1 A sample is immersed in distilled water for sufficient time to essentially fill the pores. It is then removed from the water, the water dried from the surface of the sample, and the mass (saturated) determined. When it is deemed that the sample has been in contact with water long enough to satisfy most of the absorption potential, the volume (concrete and pores) shall be determined using a displacement apparatus and the displacement of water method. Subsequently, the sample dry mass will be determined by oven drying.

4. Samples

4.1 Four samples collected from each of 2-3 areas as outlined in the field sampling procedure will be tested.

4.2 Keep the samples that are stored prior to testing in noncorrodible airtight containers at a temperature between approximately 3 and 30°C and in an area that prevents direct contact with sunlight. Samples shall be stored in such a way as to prevent or minimize moisture condensation on the insides of the containers.

4.3 The volume determination should be done as soon as practicable after maximum absorption of water has been determined to be complete.

4.4 For each measurement taken, the values including time and date, shall be recorded.

5. Apparatus

5.1 *Balance*—A balance or scale accurate, readable, and sensitive to within 0.1 % of the test load at any point within the range of use. Within any interval equal to 10 % of the capacity of the balance or scale used to determine mass, the load indication shall be accurate within 0.1 % of the difference in masses.

5.2 *Water Displacement Apparatus* -A device used to determine the volume of displacement of a sample in water. The container will have a drain from which the displaced water will be collected. The weight of water will be determined. The weight will be converted to volume using the density of water at the temperature of the water.

5.3 *Source of Heat*—A ventilated oven capable of maintaining the temperature surrounding the sample at 110 +/- 5°C (230 +/- 9°F).

5.4 *Thermometer*- With divisions of 1° C or 2°F.

6. Procedure

6.1 Determine the mass of the field sample as is to the nearest 0.1 %. Weigh and record all values.

6.2 Immerse the sample in water at room temperature until the change in mass after two successive periods is an insignificant amount (less than about 0.1 % of the mass of the sample). Measurements shall be made at 24 hour +/- increments.

6.3 Remove the test sample from the water and wipe it in a large absorbent cloth until all visible films of water are removed. A moving stream of air is permitted to assist in the drying operation. Take care to avoid evaporation of water from sample pores during the surface-drying operation. Determine the mass of the test sample in the saturated surface-dry condition to the nearest 0.1 %. Record this and all subsequent masses.

6.4 After determining the saturated-surface-dry (SSD) mass in air, immediately place the SSD test sample in the water displacement apparatus that has been prepared to measure the displacement of water. Care shall be taken to remove entrapped air from the exterior of the sample. Record the temperature of water to yield the SSD sample volume. Record mass of displaced water and convert to a volume based upon the density of water at the temperature of the water. The volume will be determined twice.

6.5 Remove the test sample from the water displacement apparatus and wipe it in a large absorbent cloth until it is essentially surfaced dried.

6.6 Weigh and record container mass. Place sample in the container (without lid) and dry the sample thoroughly in the oven. The sample is thoroughly dry when further heating causes, or would cause, less than 0.1 % additional loss in mass. Measurements shall be made at 24 hour +/- increments.

Note: Drying-Metal containers shall be used during oven drying of the samples. The container shall be clearly marked or scribed with the sample or other reference number. If multiple samples are dried in the oven at the same time a layout diagram will be used if in case the sample ID's are lost (baked off). The time required to obtain constant mass will vary depending on the type of material, size of specimen, oven type and capacity, and other factors.

6.7 After the material has dried to constant mass, remove the container/sample from the oven and replace the lid. Allow the material and container to cool to room temperature or until the container can be handled comfortably with bare hands and the operation of the balance will not be affected by convection currents and/or its being heated. Determine the mass of the dried sample and container to the nearest 0.1 %. The samples shall be stored in containers with tight fitting lids if it appears that the specimen is absorbing moisture from the air prior to determination of its dry mass. Cooling in a desiccator is acceptable in place of containers with tight fitting lids since it greatly reduces absorption of moisture from the atmosphere during cooling. Weigh and record all values.

References ASTM C 127 – 04, Standard Test Method for Density, Relative Density (Specific Gravity), and Absorption of Coarse Aggregate

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Appendix C

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APPENDIX C
LAB DATA AND CALCULATIONS

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