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Laboratory Investigation of the Use of Volcanic Ash in Concrete

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Based on the results and the subsequent analysis, it has been determined that Kansas sources of volcanic ash are not suitable for use as SCMs in concrete. Testing indicated that Kansas volcanic ash has few cementitious properties and as a result, when added to concrete, it has several possible negative effects, including increased bleed, increased set time, negative effect on strength, permeability, and finishing. The few benefits that the use of volcanic ash may provide (controlling alkali–silica reaction [ASR] and reducing shrinkage, although more testing would be necessary to completely determine the validity and extent of those benefits) are not significant enough to overcome the detrimental effects of the volcanic ash.

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Abstract

Supplementary cementitious materials (SCMs) are commonly used in KDOT concrete pavements and bridge decks to improve strength and permeability characteristics. The supplementary cementitious materials allowed under current KDOT specifications are all by-products of industrial processes. Volcanic ash is a natural product that has been used as a mineral admixture in concrete. The purpose of this study was to evaluate Kansas sources of volcanic ash for use in concrete as an SCM. This report will discuss all three stages of the study: material testing of the volcanic ash, testing the cementitious properties of Kansas volcanic ash, and evaluating the effects of volcanic ash on the properties of concrete such as strength and permeability.

Based on the results and the subsequent analysis, it has been determined that Kansas sources of volcanic ash are not suitable for use as SCMs in concrete. Testing indicated that Kansas volcanic ash has few cementitious properties and as a result, when added to concrete, it has several possible negative effects, including increased bleed, increased set time, negative effect on strength, permeability, and finishing. The few benefits that the use of volcanic ash may provide (controlling alkali–silica reaction [ASR] and reducing shrinkage, although more testing would be necessary to completely determine the validity and extent of those benefits) are not significant enough to overcome the detrimental effects of the volcanic ash.

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Chapter 1: Introduction

Supplementary cementitious materials (SCMs) are commonly used in KDOT concrete pavements and bridge decks to improve strength and permeability characteristics. The supplementary cementitious materials allowed under current KDOT specifications are all by-products of industrial processes. Volcanic ash is a natural product that has been used as a mineral admixture in concrete. The purpose of this study was to evaluate Kansas sources of volcanic ash for use in concrete as an SCM. This report will discuss all three stages of the study: material testing of the volcanic ash, testing the cementitious properties of Kansas volcanic ash, and evaluating the effects of volcanic ash on the properties of concrete such as strength and permeability.

Volcanic ash occurs in small deposits in central and western Kansas. Kansas volcanic ashes consist of small (<1 mm) particles of silica-rich rock glass that may be cemented by calcium carbonate (Carey, Frye, Plummer, & Swineford, 1952). The ash was carried into Kansas by the wind from volcanoes to the west or southwest and settled or was washed into shallow bodies of water. Volcanic ash has been mined in Kansas since the early twentieth century for use as filler in asphalt pavements, ceramic glazes, and as an abrasive. Volcanic ash from sources in Europe and the west coast of the United States has been commercially produced as a supplementary cementitious material for concrete.

Chapter 2: Methods

The three stages in the evaluation of volcanic ash for use in concrete were analysis of the volcanic ash as a material, testing of the cementitious properties of the volcanic ash, and testing of the effects of volcanic ash in concrete.

A complete evaluation of the chemical, mineralogical, and morphological properties of volcanic ash from each source was the first stage in this study. Samples of ash were collected from two different sources and the following analyses were performed on both ash samples:

- Chemical Analysis according to ASTM C311 (2005), "Standard Test Methods for Sampling and Testing Fly Ash or Natural Pozzolans for Use in Portland-Cement Concrete," including:
    - Moisture Content
    - Loss on Ignition
    - Silicon Dioxide, Aluminum Oxide, Iron Oxide, Calcium Oxide, Magnesium Oxide, Sulfur Trioxide, Sodium Oxide, and Potassium Oxide contents
- Petrographic Analysis, including:
    - Identification and quantification of glass and mineral phases present
    - Description of color and texture
- KTMR-32 (2000), "Particle Size Analysis"

The second stage was testing for effectiveness of volcanic ash as a cementitious material. ASTM C618 (2005), "Standard Specification for Coal Fly Ash and Raw or Calcined Natural Pozzolan for Use in Concrete," is the specification used to evaluate the volcanic ash. The following ASTM test methods were performed on both ash samples to determine compliance with ASTM C618:

- ASTM C430 (2008), "Standard Test Method for Fineness of Hydraulic Cement by the 45-μm (No. 325) Sieve."

- ASTM C109 (2013), “Standard Test Method for Compressive Strength of Hydraulic Cement Mortars (Using 2-in. or [50-mm] Cube Specimens).”
- ASTM C441 (2005), “Standard Test Method for Effectiveness of Pozzolans or Ground Blast-Furnace Slag in Preventing Excessive Expansion of Concrete Due to the Alkali–Silica Reaction.”
- ASTM C157 (2008), “Standard Test Method for Length Change of Hardened Hydraulic-Cement Mortar and Concrete,” with samples prepared as per ASTM C311, Section 21-23, as a mortar.

The third stage of this study was making 15 test batches of concrete in the laboratory. Prism and cylinder samples of each of the 15 mix types were cast in the laboratory and cured under standard conditions. The following tests were performed on specimens of all 15 mixes, except where noted:

- KT-73 (2010), “Density, Absorption and Voids in Hardened Concrete (‘Boil Test’).”
- AASHTO T 277 (2005), “Standard Method of Test for Electrical Indication of Concrete's Ability to Resist Chloride Ion Penetration.”
- KT-76 (2010), “Method for Testing the Compressive Strength of Molded Cylindrical Concrete Specimens.”
- ASTM C457 (1998), “Standard Test Method for Microscopical Determination of Parameters of the Air-Void System in Hardened Concrete.”
- KTMR-22 (2012), “Resistance of Concrete to Rapid Freezing and Thawing.”
- ASTM C157 (2008), “Standard Test Method for Length Change of Hardened Hydraulic-Cement Mortar and Concrete” (Free Shrinkage), with samples prepared as concrete.
- KTMR-23 (1998), “Wetting and Drying Test of Sand and Sand-Gravel Aggregate for Concrete.”

The following tests were performed on plastic concrete from all 15 mixes:

- KT-18 (2003), “Air Content of Freshly Mixed Concrete by the Pressure Method.”
- KT-20 (2002), “Mass per Cubic Foot (Meter), Yield, and Air Content (Gravimetric) of Freshly Mixed Concrete.”
- ASTM C232 (1999), “Standard Test Methods for Bleeding of Concrete.”
- KT-21 (2000), “Slump of Portland Cement Concrete.”
- KT-71 (2007), “Air-Void Analyzer.”

Chapter 3: Materials

Fifteen batches of concrete were made in the laboratory to measure the effects of volcanic ash on concrete properties. Two different mixes were used, one containing a coarse fine mix (LS) consisting of 50% limestone and 50% sand and one with total mixed aggregate (TMA) consisting of MA-2. Both were combined with volcanic ash from two sources. Cement in the mix designs was replaced with 10%, 20%, or 40% volcanic ash. The testing matrix for this stage is shown in Table 3.1.

Table 3.1: Testing Matrix of Concrete Mixes for Stage 3

Batch	Date Cast	Coarse Aggregate	Volcanic Ash Replaced Cement, %	Volcanic Ash Sample No.
L1-0	1/21/2010	LS-1	0	
L1-20-1	1/21/2010	LS-1	20	09-0809
L1-40-1	1/26/2010	LS-1	40	09-0809
T1-0	1/26/2010	TMA-1	0	
T1-20-1	2/4/2010	TMA-1	20	09-0809
T1-40-1	2/4/2010	TMA-1	40	09-0809
T1-20-2	2/18/2010	TMA-2	20	09-0808
T2-40-2	2/18/2010	TMA-2	40	09-0808
T1-0	2/25/2010	TMA-1	0	
T2-20-2	2/25/2010	TMA-2	20	09-0808
L2-20-2	3/4/2010	LS-2	20	09-0808
L2-40-2	3/18/2010	LS-2	40	09-0808
L2-0	3/25/2010	LS-2	0	
L2-40-2	4/4/2010	LS-2	40	09-0808
L2-10-2	4/22/2010	LS-2	10	09-0808

The ash represented by Sample Number 09-0808 was from Adams Pits in Pratt County, Kansas. This ash is 95% glass shards and 5% rounded quartz grains. The ash represented by Sample Number 09-0809 was from Schoeppel Silica in Trego County, Kansas. This is a very clean volcanic ash that consists of 99% glass shards.

The limestone coarse aggregate used in combination with the volcanic ash was a Class 1 limestone that met the CA-6 gradation from Mid-States Materials. This aggregate was produced from the Ervine Creek Ledge of the Plummers Creek Quarry in Osage County, Kansas. The fine aggregate used in the limestone mixes was an FA-1 sand from Klotz Sand, south of Lakin in Kearny County, Kansas. The limestone mix was a 50:50 mix. The total mixed aggregate used was a sand/sand gravel from Klotz Sand that met the MA-2 gradation. Table 3.1 lists two samples of both limestone and TMA. In both cases, this is a second sample obtained of each rock from the same locations in order to finish the outline mixes.

Chapter 4: Results and Discussion

4.1 Stage 1: Volcanic Ash Material Testing

As described, material testing performed on the volcanic ash samples consisted of ASTM C311, a petrographic analysis, and KTMR-32. The chemical analysis, ASTM C311, reported that Sample 09-0808 primarily consisted of 75.75% silicon oxide (SiO_2) and 11.00% aluminum oxide (Al_2O_3). Sample 09-0809 primarily consisted of 72.10% silicon oxide (SiO_2) and 13.23% aluminum oxide (Al_2O_3). The petrographic analysis performed indicated that Sample 09-0808 consisted of approximately 95% glass shards. Sample 09-0809 consisted of approximately 99% glass shards. The particle size analysis (KTMR-32), along with the ATSM C311 and petrographic reports, are included in Appendix A. The chemical, petrographic, and particle size analyses are all consistent with historical analyses of Kansas volcanic ash performed by the Kansas Geologic Survey (Carey, Frye, Plummer, & Swineford, 1952).

4.2 Stage 2: Cementitious Properties of Volcanic Ash

The specification used to evaluate the cementitious properties of the volcanic ash was ASTM C618. Test methods ASTM C430, ASTM C109, ASTM C441, and ASTM C157 are the methods used to determine the compliance of the sample with ASTM C618. Complete results for all of these tests can be found in Appendix B. In this section, ASTM C157 was used to evaluate the length change properties of the volcanic ash as a cementitious mortar. ASTM C157 was also used in Stage 3 to determine the length change of concrete with volcanic ash as a SCM.

Volcanic Ash Sample 09-0808 failed the ASTM C430 and ASTM C109 portions of ASTM C618. ASTM C430 indicated that the sample contained approximately 30% more material retained on the No. 325 sieve than specified. ASTM C109 indicated that the sample did not meet the minimum 75% of control strength at both 7 and 28 days (sample was 56% and 64%, respectively). The sample also exceeded the maximum 105% of control for the water requirement (108%).

Volcanic Ash Sample 09-0809 failed the ASTM C109 and ASTM C157 portions of ASTM C618. The sample had strengths of 63% and 73% of control and a water requirement of

107% of control. The control cement used for comparison of both volcanic ash samples was Monarch Type I/II with a lab number of 08-1042. Table 4.1 outlines these results.

Table 4.1: Stage 2 Cementitious Properties Results Sample 09-0809

ASTM	Result Sample 09-0808	Result Sample 09-0809	Requirement per ASTM C618
C430	63.5%[1]	21.4%[1]	34% Max
C109 (7 days)	56%[2]	63%[2]	75% Min
C109 (28 days)	64%[2]	73%[2]	75% Min
C109 (water)	108%[2]	107%[2]	105% Max
C441	47%[2]	27%[2]	120% Max
C157	0.003	0.008	0.03 Max

[1] Value is percent retained
[2] Value is percent of control

It can be concluded based on these results that Kansas sources of volcanic ash should not be used as a cementitious material. Both samples passed ASTM C441 and ASTM C157, indicating that the material could be used to reduce either alkali–silica reaction (ASR) or shrinkage. These properties are investigated further in Stage 3.

4.3 Stage 3: Effects of Volcanic Ash on Concrete Properties

4.3.1 KT-73, AASHTO T 277, KT-76

The results of Stage 3 testing of the effects of volcanic ash on the properties of concrete are given in this section. Results for KT-73, AASHTO T 277, and KT-76 are presented in Table 4.2. KT-73, known as the "Boil Test," measures the volume of permeable pore space in a concrete sample. It is used by KDOT as a concrete permeability test along with AASHTO T 277, known as the rapid chloride permeability test (RCPT). KT-76 measures the compressive strength of concrete cylinders. KDOT specifications require that for standard concrete, KT-73 must be less than 12.5% at 28 days, AASHTO T 277 must be less than 3,500 C at 56 days, and KT-76 must be greater than 4,000 psi at 28 days (KDOT, 2007, Division 400: Concrete). Only six of the 15 concretes passed KT-73, three concretes passed AASHTO T 277, and 10 concretes passed

KT-76 at 28 days. KT-76 was also run on samples at 56 days of age for Batches 12–15. The decision to add those tests was made to determine if there was a significant strength gain due to a delayed pozzolanic reaction of the volcanic ash.

Table 4.2: Stage 3 Permeability and Strength Test Results

Batch	KT-73 Boil %	AASHTO T 277 RCPT, C	KT-76 Strength, psi (28 Day)	KT-76 Strength, psi (56 Day)
L1-0	12.4	5,198	6,015	N/A
L1-20-1	12.8	4,028	4,830	N/A
L1-40-1	14.4	2,251	4,250	N/A
T1-0	9.9	2,882	5,830	N/A
T1-20-1	11.7	4,692	4,620	N/A
T1-40-1	12.6	4,916	3,260	N/A
T1-20-2	13.3	6,229	2,570	N/A
T1-40-2	13.1	7,115	2,910	N/A
T1-0	11.6	4,849	5,320	N/A
T2-20-2	12.2	5,417	3,850	N/A
L2-20-2	13.0	3,662	5,000	N/A
L2-40-2	13.7	4,664	3,120	3,310
L2-0	13.0	3,356	5,400	5,680
L2-40-2	13.7	3,556	5,080	3,970
L2-10-2	11.9	5,080	4,810	5,410

Table 4.3 outlines the boil, RCPT, and Strength results based on batches containing limestone and percentage of volcanic ash. The percent change values presented are based on the zero percent volcanic ash control batches. Note that beneficial results would be a decrease in boil and RCPT but an increase in strength. Table 4.4 displays the same information for batches containing TMA.

Table 4.3: Boil, RCPT, and Strength Percent Change for Batches Containing Limestone

Percent Volcanic Ash	0	10	20	40
Average Boil, %	12.7	11.9	12.9	13.9
Percent Change (±)	-	-6%	2%	10%
Average RCPT, C	4,277	5,080	3,845	3,490
Percent Change (±)	-	19%	-10%	-18%
Average Strength at 28 days, psi	5,710	4,810	4,915	4,150
Percent Change (±)	-	-16%	-14%	-27%

Table 4.4: Boil, RCPT, and Strength Percent Change for Batches Containing TMA

Percent Volcanic Ash	0	20	40
Average Boil, %	10.8	12.4	12.9
Percent Change (±)	-	15%	20%
Average RCPT, C	3,866	5,446	6,016
Percent Change (±)	-	41%	56%
Average Strength at 28 days, psi	5,575	3,680	3,085
Percent Change (±)	-	-34%	-45%

As expected based on the Stage 2 testing, the addition of Kansas volcanic ash to concrete in large proportions had a significant effect on these tests. KT-73 Boil Test results indicate that the addition of more than 10% volcanic ash increases permeability. AASHTO T 277 RCPT results indicate that the addition of volcanic ash improves RCPT (decreases permeability) in limestone mixes but increases permeability in TMA mixes. The variation in these results would indicate that more testing should be done. However, given the best-case scenario, limestone with 40% volcanic ash with an 18% reduction in RCPT, the results barely passed KDOT's 3,500 C requirement. This would not be sufficient to overcome the significant reduction in strength as measured by KT-76 or in the increase in the boil results. The combination of these three tests, not considering other results, would indicate that Kansas volcanic ash is not suitable for use as a replacement of cement in concrete.

4.3.2 ASTM C457 and KTMR-22

Results for ASTM C457 (percent air and spacing factor) and KTMR-22 (durability factor and expansion) are presented in Table 4.5. KDOT does not specify the hardened air percent or spacing factor as tested by ASTM C457. KDOT specifies these values based on plastic concrete testing. KTMR-22 determines the resistance to rapid freezing and thawing of concrete. KTMR-22 follows ASTM C666 (1997) Procedure B, with the following exceptions:

- Use the following proportioning of materials and specific types of materials as stated:
    - 25% -3/4” +1/2” (saturated surface dry [SSD] by toweling)
    - 25% -1/2” +3/8” (SSD by toweling)
    - 50% FA-A (correction made for moisture) Kaw River sand
    - Yield cement factor (Y.C.F.) 601.60 lbs/yd^3
    - Water–cement ratio (w/c) 0.4431 to 0.4874 (tap water) (Monarch Cement, Type II)
    - Air 5 to 7% (A.E.A. Air Tite by Gifford-Hill)
    - Slump 1½” to 2½”
    - Total volume approximately 0.6 ft^3 concrete
- For this test the specimens shall be cured for 90 days as follows:
    - Place beams in a moisture room for 67 days.
    - Transfer beams to a room having a relative humidity of approximately 50% and a temperature of approximately 73 °F for 21 days.
    - Place beams in a tempering tank maintained at 70 °F for 24 hours.
    - Place beams in a tempering tank maintained at 40 °F for 24 hours.

KDOT Specifications require KTMR-22 only on concrete containing limestone or dolomite aggregates; however, it was run on all batches in this study for consistency. The specifications require that the durability factor be greater than 95 and the expansion be less than 0.025%. KDOT defines the durability factor and expansion at 300 freeze-thaw cycles per ASTM C666 (KDOT, 2007). No correlation between the KTMR-22 results and the amount of volcanic ash present in the mix is obvious. The variation in results from batch to batch is within the precision of the test.

Table 4.5: Stage 3 Air Void System and Freeze-Thaw Durability Test Results

Batch	ASTM C457 % air[1]	C457 Spacing Factor, mm[1]	KTMR-22 Durability Factor	KTMR-22 Expansion, %
L1-0	11.90	0.089	97	0.019
L1-20-1	9.30	0.148	100	0.016
L1-40-1	6.20	0.159	97	0.008
T1-0	7.85	0.135	98	0.002
T1-20-1	7.60	0.121	100	0.007
T1-40-1	8.55	0.122	100	0.008
T1-20-2	16.45	0.092	100	0.009
T1-40-2	12.60	0.097	100	0.007
T1-0	8.50	0.127	100	0.012
T2-20-2	8.45	0.133	100	0.006
L2-20-2	8.80	0.105	98	0.004
L2-40-2	13.85	0.095	100	0.012
L2-0	12.30	0.075	97	0.020
L2-40-2	8.20	0.107	100	0.010
L2-10-2	11.05	0.093	100	0.009

[1] Average of two cylinders

4.3.3 ASTM C157

The length change of hardened concrete was measured according to ASTM C157, commonly referred to as free shrinkage. In Stage 3, ASTM C157 was used to measure the strain in concrete due to shrinkage. The procedure used for these tests is ASTM C157 with four minor exceptions. The first exception was that six prisms were cast instead of the required three. The other variations include the curing temperature, the length of time the samples were cured, and the frequency at which readings were taken, as described next.

Prisms were cast and cured for 24 hours in a moist room, then were removed from the molds and placed in a lime-saturated solution maintained at 73±3 °F. An initial length reading was taken, and then the prisms were returned to a lime-saturated solution and placed in the moist room for humidity (100%) and temperature control. Each prism was placed in a lime-saturated solution while the other specimens were being taken out of the molds. When all prisms had been demolded, the initial readings were taken. For all samples, after the initial readings were taken, three of the samples were cured in the lime-saturated solution for 7 days and the second set of three prisms were cured for 14 days. All specimens were kept in the lime-saturated solution in the moist room for temperature control purposes. When the prisms were removed from the lime-saturated solution, three at 7 days and three at 14 days, a measurement was taken for each prism. The prisms were then placed in a temperature- and humidity-controlled room at 70±3 °F and 50±4% relative humidity.

The following time descriptions refer to the specimen age from the cast date. For the first 30 days, a reading was taken Monday through Friday. After 30 days, a reading was taken three times a week, on Monday, Wednesday, and Friday, until the specimens reached 90 days of age. After 90 days, a reading was taken once a week on Monday until the age of 180 days. For the remainder of the 365 days, a reading was taken on the first of each month. A comparator was used to measure the length. The comparator was zeroed with a reference bar and then the measurement on the prism was recorded. The shrinkage of each prism was calculated based on the initial reading taken on the day of demolding. Strain values were calculated by dividing the change in length (from the initial reading) by the overall length of the prism. Plots of these strain values over specimen age are presented in Appendix C. Plots for Batches 2, 3, and 4 are not included because an initial reading at the time of removal from the molds was not taken, therefore a change in length could not be determined. However, the length change of the prisms over 365 days was still recorded. It would be possible to obtain an estimate of the strain in these prisms by taking the first reading after the specimens were removed from the lime solution as the initial reading. This would only be an estimate as the prisms underwent shrinkage while they were curing that would not be accounted for.

The results of ASTM C157 would indicate that the addition of Kansas volcanic ash did not significantly affect the shrinkage. Batches containing 40% volcanic ash did tend to experience a larger amount of strain at 365 days, but strain values for all samples at around 30 days were consistently similar.

4.3.4 KTMR-23

The KTMR-23 Wetting and Drying Test is used to determine the resistance to ASR of sand and sand-gravel aggregates to be used in concrete construction. In this study, KTMR-23 was used to determine if the addition of volcanic ash would promote or reduce ASR with aggregate that would otherwise pass KTMR-23. KTMR-23 measures both the percent expansion and modulus of rupture of concrete prisms. Six prisms are cast, three of which are tested for modulus of rupture at 60 days and the other three at 365 days. The percent expansion is read on the prisms at intervals of 30, 60, 120, 180, 240, 300, and 365 days (note that only one set of three prisms is read beyond 60 days as the first set is used to test for modulus of rupture). KDOT specifications require that the prisms have a minimum modulus of rupture of 550 psi at both 60 and 365 days; maximum percent expansion shall not exceed 0.050% at 180 days and 0.070% at 365 days. Results for KTMR-23 (modulus of rupture) are presented in Table 4.6. Results for KTMR-23 (percent expansion) are presented in Appendix D.

Table 4.6: Stage 3 KTMR-23 Modulus of Rupture Test Results

Batch	KTMR-23 Modulus of Rupture at 60 days, psi	KTMR-23 Modulus of Rupture at 365 days, psi	KTMR-23 Expansion at 365 days, %
L1-0	829	780	0.019
L1-20-1	580	738	0.016
L1-40-1	791	324	0.008
T1-0	696	904	0.002
T1-20-1	689	602	0.007
T1-40-1	562	635	0.008
T1-20-2	444	410	0.009
T1-40-2	438	593	0.007
T1-0	722	693	0.012
T2-20-2	635	910	0.006
L2-20-2	726	839	0.004
L2-40-2	541	642	0.012
L2-0	806	832	0.020
L2-40-2	700	798	0.010
L2-10-2	700	745	0.009

Results from KTMR-23 would indicate that, while not a significant factor, the addition of more than 20% Kansas volcanic ash could be detrimental to the modulus of rupture and/or the expansion. All but one batch containing 40% volcanic ash failed at least one of the rupture tests and Batch L1-40-1 failed the 365-day rupture and the percent expansion. However, with regard to the percent expansion values, all batches, with the exception of L1-40-1, consistently passed at both 180 and 365 days.

4.3.5 KT-18, KT-20, ASTM C232, KT-21, and KT-71

KT-18, KT-20, ASTM C232, KT-21, and KT-71 were run on plastic concrete for all batches. Results for KT-20 (Unit Weight), KT-18 (Air Content), KT-21 (Slump), and KT-71 (Spacing Factor) are given in Table 4.7. Results for ASTM C232 (Bleed Test) are presented in Appendix E. The bleed test showed that adding ash significantly delayed setting times and increased bleeding. Increased bleeding increases water loss during curing and can negatively affect the strength and permeability of hardened concrete. Excess bleed water also causes finishing issues.

Table 4.7: Stage 3 Plastic Concrete Test Results

Batch	KT-20 Unit Weight, lb/ft^3	KT-18 Air Content	KT-21 Slump, inches	KT-71 AVA Spacing Factor, mm
L1-0	138.7	8.00%	2.5	0.080
L1-20-1	138.1	9.00%	3.0	0.136
L1-40-1	140.6	6.25%	1.75	0.155
T1-0	141.2	7.25%	1.75	0.122
T1-20-1	140.1	7.75%	2.0	0.130
T1-40-1	137.0	9.00%	2.0	0.111
T1-20-2	-	17.25%	9.0	0.090
T1-40-2	133.5	9.00%	2.5	0.107
T1-0	142.0	6.50%	-	0.132
T2-20-2	-	8.50%	-	0.141
L2-20-2	139.4	7.25%	2.25	0.096
L2-40-2	131.0	11.75%	4.0	0.086
L2-0	138.0	9.00%	4.0	-
L2-40-2	138.5	8.00%	1.5	0.105
L2-10-2	-	8.00%	5.25	0.086

The results for these tests do not give an indication of the effectiveness of Kansas volcanic ash in concrete. By the very nature of some of these tests, they are highly dependent on several variables not related to SCMs and can vary from minute to minute during the mixing process. Additionally, due to some of the irregularities experienced while performing these tests, it has been determined that the results should be for information only and not included in the analysis of Kansas volcanic ash.

Chapter 5: Conclusion

Based on the results and the subsequent analysis, it has been determined that Kansas sources of volcanic ash are not suitable for use as SCMs in concrete. Testing indicated that Kansas volcanic ash has few cementitious properties and as a result, when added to concrete, it has several possible negative effects, including increased bleed, increased set time, negative effect on strength, permeability, and finishing. The few benefits that the use of volcanic ash may provide (controlling alkali–silica reaction [ASR] and reducing shrinkage, although more testing would be necessary to completely determine the validity and extent of those benefits) are not significant enough to overcome the detrimental effects of the volcanic ash.

References

AASHTO T 277-05. (2005). *Standard method of test for electrical indication of concrete's ability to resist chloride ion penetration*. Washington, DC: American Association of State Highway and Transportation Officials.

ASTM C109 / C109M-13e1. (2013). *Standard test method for compressive strength of hydraulic cement mortars (using 2-in. or [50-mm] cube specimens)*. West Conshohocken, PA: ASTM International. doi: 10.1520/C0109_C0109M-13E01, www.astm.org

ASTM C157 / C157M-08. (2008). *Standard test method for length change of hardened hydraulic-cement mortar and concrete*. West Conshohocken, PA: ASTM International. doi: 10.1520/C0157_C0157M-08, www.astm.org

ASTM C232-99. (1999). *Standard test methods for bleeding of concrete*. West Conshohocken, PA: ASTM International. doi: 10.1520/C0232-99, www.astm.org

ASTM C311-05. (2005). *Standard test methods for sampling and testing fly ash or natural pozzolans for use in portland-cement concrete*. West Conshohocken, PA: ASTM International. doi: 10.1520/C0311-05, www.astm.org

ASTM C430-08. (2008). *Standard test method for fineness of hydraulic cement by the 45-μm (No. 325) sieve*. West Conshohocken, PA: ASTM International. doi: 10.1520/C0430-08, www.astm.org

ASTM C441-05. (2005). *Standard test method for effectiveness of pozzolans or ground blast-furnace slag in preventing excessive expansion of concrete due to the alkali-silica reaction*. West Conshohocken, PA: ASTM International. doi: 10.1520/C0441-05, www.astm.org

ASTM C457-98. (1998). *Standard test method for microscopical determination of parameters of the air-void system in hardened concrete*. West Conshohocken, PA: ASTM International. doi: 10.1520/C0457-98, www.astm.org

ASTM C618-05. (2005). *Standard specification for coal fly ash and raw or calcined natural pozzolan for use in concrete*. West Conshohocken, PA: ASTM International. doi: 10.1520/C0618-05, www.astm.org

ASTM C666-97. (1997). *Standard test method for resistance of concrete to rapid freezing and thawing*. West Conshohocken, PA: ASTM International. doi: 10.1520/C0666-97, www.astm.org

Carey, J.S., Frye, J.C., Plummer, N., & Swineford, A. (1952). Kansas volcanic ash resources. *Kansas Geological Survey, Bulletin 96, Part 1*. Retrieved from http://www.kgs.ku.edu/Publications/Bulletins/96/index.html

Kansas Department of Transportation (KDOT). (2007). *Standard specifications for state road & bridge construction*. Retrieved from http://www.ksdot.org/burConsMain/specprov/2007SSDefault.asp

KT-18 Kansas Test Method. (2003). Air content of freshly mixed concrete by the pressure method. *Kansas Department of Transportation construction manual, Part V*. Topeka, KS: Kansas Department of Transportation.

KT-20 Kansas Test Method. (2002). Mass per cubic foot (meter), yield, and air content (gravimetric) of freshly mixed concrete. *Kansas Department of Transportation construction manual, Part V*. Topeka, KS: Kansas Department of Transportation.

KT-21 Kansas Test Method. (2000). Slump of portland cement concrete. *Kansas Department of Transportation construction manual, Part V*. Topeka, KS: Kansas Department of Transportation.

KT-71 Kansas Test Method. (2007). Air-void analyzer. *Kansas Department of Transportation construction manual, Part V*. Topeka, KS: Kansas Department of Transportation.

KT-73 Kansas Test Method. (2010). Density, absorption and voids in hardened concrete ("Boil Test"). *Kansas Department of Transportation construction manual, Part V*. Topeka, KS: Kansas Department of Transportation.

KT-76 Kansas Test Method. (2010). Method for testing the compressive strength of molded cylindrical concrete specimens. *Kansas Department of Transportation construction manual, Part V*. Topeka, KS: Kansas Department of Transportation.

KTMR-22 Kansas Test Method. (2012). *Resistance of concrete to rapid freezing and thawing*. Topeka, KS: Kansas Department of Transportation.

KTMR-23 Kansas Test Method. (1998). *Wetting and drying test of sand and sand-gravel aggregate for concrete*. Topeka, KS: Kansas Department of Transportation.

KTMR-32 Kansas Test Method. (2000). *Particle size analysis.* Topeka, KS: Kansas Department of Transportation.

Appendix A: Stage 1 Volcanic Ash Material Test Results

Volcanic Ash Report Sheet

Analyst 1/25/2010

Lab. No: 09-0808

Mgf: R. A. M.

Type: Volcanic Ash

Moisture Content		Insoluble Residue	
Weight of Porcelain Crucible →	7.3809	Weight of Sample →	1.0000
Wt of Crucible & Sample →	10.2957	Wt of Empty Porcelain Crucible →	7.9619
Wt of Cruc & Spl after Hting →	10.2570	Wt of Pocelain Cruc & Spl after Ign →	8.8155
Percent Moisture Loss →	1.3277	Percent Insoluble Residue →	85.3600

SiO_2 →	75.57%
Al_2O_3 →	11.00%
Fe_2O →	1.94%
CaO →	0.78%
MgO →	0.21%
SO_3 →	0.51%
Na_2O →	0.45%
K_2O →	4.36%
Mn_2O_3 →	0.08%
P2O5 →	0.01%
Cr2O3 →	0.77%
SrO →	0.03%
TiO2 →	0.27%
ZnO →	0.04%
L.O.I. →	2.69%
Moisture Content →	1.33%
Insouluble Residue →	85.36%

Analyzed By:____________

Checked By:____________

1

Figure A.1: ASTM C311 Chemical Composition Report for Volcanic Ash Sample 09-0808

KANSAS DEPARTMENT OF TRANSPORTATION

ROUTINE TESTS

CMS No. ____________

Date 6-9-09

Lab. No. 09-808

Technician ____________

Sample No. ____________

REMARKS
50g VOLCANIC ASH
Correction "A"
Cyl.# 2

ASTM - D422 Hydrometer and Sieve Analysis				
	Sieve Number	Grams Retained	Percent Retained	Percent Passing
375 mm	11/2"	0	0	100
19 mm	3/4"	0	0	100
9.5 mm	3/8"	0	0	100
4.75 mm	4	0	0	100
2.00 mm	10	0	0	100
550um	20	.04	0	100
425um	40	.17	0	100
250um	60	.94	2	98
150um	100	4.89	10	90
75um	200	17.81	36	64

Temp. °C..	Hydro. Reading	Hydro Correction	Period of Sedimentation	mm max. Grain size	mm Actual Grain Size	Percent in Suspension
74.8			Min. 0.0			
	35	5.60	0.5	.112	0.0592	58
	29	5.60	1.0	.078	0.0436	46
74.8	23	5.60	2.0	.055	0.0321	34
74.9	16	5.58	5.0	.035	0.0213	21
74.9	11	5.58	15.0	.020	0.0126	11
74.8	9	5.60	30.0	.014	0.0090	7
74.7	8	5.63	60.0	.010	0.0064	5
75.4	7	5.45	250.0	.005	0.0032	3
75.6	6	5.40	1440.0	.002	0.0013	1

AASHTO - T100 SPECIFIC GRAVITY	
Flask	1
Temp. °C F	76
Dry Wt. of Soil	25
Wt. Flask and Water	347.29
Wt. Flask, Water, Soil	361.75
Difference	14.46
"K" for Temp	.99901
Specific Gravity @ 20° C	2.37

Hygroscopic Moisture	
Pan No.	
Pan and Wet Soil	
Pan and Dry Soil	
Wt. of Pan	
Wt. of Dry Soil	
Wt. of Water	
% Water	

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Figure A.2: KTMR-32 Particle Size Analysis Results for Volcanic Ash Sample 09-0808

Kansas Department of Transportation

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2300 S. W. Van Buren, Topeka, Kansas 66611-1195
Telephone - (785) 291-3037
Fax # - (785) 296-2526

MEMORANDUM

TO: Rod Montney, P.E., Concrete Research Engineer

FROM: Randy Billinger, P.G., Research Geologist

DATE: June 10, 2009

SUBJECT: Volcanic Ash Sample MRC 09-0808

This volcanic ash sample is a stock pile sample from the Adams Pits in Pratt County and was sampled on April 8, 2009. The sample as received is a powder sample with a few friable, loosely cemented clumps which break apart with light finger pressure. The Munsell color is 10YR 7/2 or light gray. Some smaller lighter gray-white clumps were noted in the sample. The volcanic ash sample consists of approximately 95% glass shards. The shards are mostly angular to sub-angular. The remaining 5 % consists predominantly of rounded quartz grains with minor calcite, feldspar and mafic minerals.

cc: Morris Hunt, Soil Survey Specialist
Richard McReynolds, P.E., Engineer of Research
Joshua Welge, P.E., Engineer of Tests

Figure A.3: Petrographic Analysis Report for Volcanic Ash Sample 09-0808

Volcanic Ash Report Sheet

Analyst: [signature] 6/12/2009

Lab. No: 09-0809

Mgf: R. A. M.

Type: Volcanic Ash

Percent Moisture Content		Loss on Ignition (L.O.I.)	
Wt of Empty Porcelain Cruc →	10.9654	Weight of Empty Pt Crucible →	25.1738
Wt of Porcelain Cruc & Smpl →	15.1978	Wt of Pt Crucible & Sample →	29.5616
Wt of Cruc & Smpl after Hting →	15.1134	Wt of Pt Cruc & Spl after Ign →	29.3080
Percent Moisture →	1.9941	Loss on Ignition →	5.7797

SiO_2 →	72.10%
Al_2O_3 →	13.23%
Fe_2O →	2.33%
CaO →	0.52%
MgO →	nil
SO_3 →	0.19%
Na_2O →	2.35%
K_2O →	5.36%
Mn_2O_3 →	0.07%
P_2O_5 →	nil
Cr_2O_3 →	0.02%
SrO →	0.19%
TiO_2 →	0.23%
ZnO →	0.03%
L.O.I. + Moisture Content →	5.78%
Percent Moisture Content →	1.99%
L.O.I. →	3.79%
Total →	100.37%

Analyzed By:______________

Checked By:______________

1

Figure A.4: ASTM C311 Chemical Composition Report for Volcanic Ash Sample 09-0809

KANSAS DEPARTMENT OF TRANSPORTATION

ROUTINE TESTS

CMS No. ______

Date ______ Lab. No. 09-0809

Technician ______ Sample No. ______

REMARKS: 50g Volcanic Ash

Correction "A":

Cyl.# 1

ASTM - D422 Hydrometer and Sieve Analysis	Sieve Number	Grams Retained	Percent Retained	Percent Passing
375 mm	11/2"	0	0	100
19 mm	3/4"	0	0	100
9.5 mm	3/8"	0	0	100
4.75 mm	4	0	0	100
2.00 mm	10	0	0	100
550um	20	.08	0	100
425um	40	.20	0	100
250um	60	.35	1	99
150um	100	.82	2	98
75um	200	4.53	9	91

Temp. °C..	Hydro. Reading	Hydro Correction	Period of Sedimentation	mm max. Grain size	mm Actual Grain Size	Percent in Suspension
74.4			Min. 0.0			
	48	5.70	0.5	.112	0.0572	98
	43	5.70	1.0	.078	0.0423	80
74.5	38	5.68	2.0	.055	0.0313	69
74.5	32	5.68	5.0	.035	0.0208	57
74.6	19	5.65	15.0	.020	0.0131	29
74.5	13	5.68	30.0	.014	0.0096	16
74.5	10	5.68	60.0	.010	0.0069	9
74.2	7	5.75	250.0	.005	0.0034	3
75.2	6	5.50	1440.0	.002	0.0014	1

AASHTO - T100 SPECIFIC GRAVITY	
Flask	2
Temp. °C F	76
Dry Wt. of Soil	25
Wt. Flask and Water	353.69
Wt. Flask, Water, Soil	368.21
Difference	14.52
"K" for Temp	.99901
Specific Gravity @ 20° C	2.38

Hygroscopic Moisture	
Pan No.	
Pan and Wet Soil	
Pan and Dry Soil	
Wt. of Pan	
Wt. of Dry Soil	
Wt. of Water	
% Water	

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Figure A.5: KTMR-32 Particle Size Analysis Results for Volcanic Ash Sample 09-0809

Kansas Department of Transportation

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Fax # - (785) 296-2526

MEMORANDUM

TO: Rod Montney, P.E., Concrete Research Engineer

FROM: Randy Billinger, P.G., Research Geologist

DATE: June 10, 2009

SUBJECT: Volcanic Ash Sample MRC 09-0809

This volcanic ash sample is a stock pile sample from Schoeppel Silica in Trego County and was sampled on April 14, 2009. The sample as received is a powder sample mixed with friable, loosely cemented clumps which break apart with light finger pressure. The Munsell color is 5YR 8/1 which is a color hue of white. The volcanic ash sample consists of approximately 99% glass shards. The shards are mostly angular to sub-angular. The remaining 1 % consists predominantly of rounded quartz grains. As received, this is a very clean sample of volcanic ash.

cc: Morris Hunt, Soil Survey Specialist
Richard McReynolds, P.E., Engineer of Research
Joshua Welge, P.E., Engineer of Tests

Figure A.6: Petrographic Analysis Report for Volcanic Ash Sample 09-0809

Appendix B: Stage 2 Volcanic Ash Cementitious Property Test Results

KANSAS DEPARTMENT OF TRANSPORTATION   Page 1 of 5
Report of sample of FLY ASH - Class: ______ (C/F)
VOLCANIC ASH

WORKSHEET FOR COMPLETE TESTING
OF FLYASH. 2007 SMS 2004, ASTM C-618

Laboratory No 09-0808
Date Rep'td.
Date Rec'd. 12-2-09

Specification No. ______ Quantity ______
Source of material ______
Sample from ______
Submitted by HEATHER McCLOAD
Identification marks ______ Field Lab No ______
Project NO. ______
Type of construction RESEARCH
Contractor ______

SUMMARY OF PHYSICAL TESTS

	Result	ASTM C-618 Specifications
Fineness-No.325 wet-sieve (% retained)	63.5 [1	34 max
Strength Activity Index -		
With portland cement @ 7 days (% of control)	56 [0 (e)	75 min
With portland cement @28 days (% of control)	64 [0 (e)	75 min
Water requirement (% of control)	108 [0	105 max
Soundness-autoclave expansion (%)	— [2	0.8 max
Density (g/cm³)	2.38 [2	none
Multiple Factor-loss on ignition x 325 fineness (%)	[1 (a)	255 max
Increase of Drying Shrinkage of mortar bars @28 days (%)	0.003 [3	0.03 max

Effectiveness in Controlling Alkali Silica-Reactions

Expansion of Test as % of Control @ 14 Days ...... 47 [0   120 max
Fly Ash as % of total cem + ash .... 15 %
Alkali content of cement used .... 0.55 %
Cement used and Lab Number: . . . . Monarch I/II 08-1042

Number of decimal places to report = [N

NOTE: ASTM C-618 covers Class C and F fly ashes.
(a) specified for Class F only.
(e) meeting the 7 or 28 day indicates specification compliance.

120 max. for use in Concrete, and Concrete Pipe.

Figure B.1: Summary of ASTM C618 for Volcanic Ash Sample 09-0808

TEST OF FLY ASH Specification ASTM C-618 Lab No. 09-0808

DENSITY

Test Method ASTM C-311 sec. 17 & C-188

Flask No. 1

Reference Flask - start 0.0
finish 0.0
change 0.0

Final Flask Reading (ml) 21.5
Correction for Ref. change ... 0.0
Initial Flask Reading (ml) ... 0.5
Volume Displaced (ml) * 21.0
Sample Weight (gm) 50.00

Density (gm/cm^3) = 50 / volume displaced = 2.38

*** Final - Initial**

ml	density	ml	density	ml	density	ml	density	ml	density
17.5	= 2.86	18.3	= 2.73	19.1	= 2.62	19.9	= 2.51	20.7	= 2.42
17.6	= 2.84	18.4	= 2.72	19.2	= 2.60	20.0	= 2.50	20.8	= 2.40
17.7	= 2.82	18.5	= 2.70	19.3	= 2.59	20.1	= 2.49	20.9	= 2.39
17.8	= 2.81	18.6	= 2.69	19.4	= 2.58	20.2	= 2.48	21.0	= 2.38
17.9	= 2.79	18.7	= 2.67	19.5	= 2.56	20.3	= 2.46	21.1	= 2.37
18.0	= 2.78	18.8	= 2.66	19.6	= 2.55	20.4	= 2.45	21.2	= 2.36
18.1	= 2.76	18.9	= 2.65	19.7	= 2.54	20.5	= 2.44	21.3	= 2.35
18.2	= 2.75	19.0	= 2.63	19.8	= 2.53	20.6	= 2.43	21.4	= 2.34

FINENESS BY #325 SIEVE

Test Method ASTM C-311 sec. 19.1 & C-430

Sieve Correction Factor .... (-0.54)
Sample Size (gm) 1.0000
Amount Retained (gm) 0.6403
Fineness = (0.6403 x 100) + (-0.54) = 63.49 % **Retained**

Fineness = (gm. ret x 100) + sieve correction factor

MULTIPLE FACTOR

Specification ASTM C-618 Table 2a

Note: The multiple factor is calculated as the product of the loss on ignition and the fineness amount retained on the # 325 sieve.

L = loss on ignition = ________ %

F = fineness, % ret. = 63.49 %

MULTIPLE FACTOR = L X F = ________ x 63.49 = ________

Figure B.2: ASTM C430 for Volcanic Ash Sample 09-0808

TEST OF FLY ASH Specification ASTM C-618 Lab No. 09-0808

STRENGTH ACTIVITY INDEX WITH PORTLAND CEMENT

Test Method ASTM C-311 sec. 25 - 28 and C-109

Mix:

	Control	Test
Cement (**Monarch I/II** 08-1042) - gm	500	400
Fly Ash (Test sample) - gm	none	100
Sand (Standard -Graded C109) - gm	1375	1375
Water (distilled) - ml	242	262 255 245 230
Flow % (25 drops, test +/- 5 of control)	123.5	125 110 93 58
No. of specimens	6	6
Date / Time 12-7-09	7:30	8:35 8:20 8:05 7:55

Lab Temp & R.H. .... 71 °F & 57 %R.H.
Mixed by .... D.H/D.L

Cure: Dates

Moist Cure all specimens, in molds, for 1 day until ... 12 - 8 - 09
Then in **Lime Saturated Water Cure** (C-109)
Test half the specimens @ 7 days age .... 12 - 14 - 09

Test the remaining specimens @ 28 days age .... 1 - 4 - 10

Test: Compressive Strength (lbs)

	7 Day		28 Day	
	Control (B)	Test (A)	Control (B)	Test (A)
(1)	18871	10109	24581	15875
(2)	18402	10433	25385	15737
(3)	18954	10875	25007	16587
Avg (psi)*	4686	2618	6248	4017

* (1+2+3)/12= avg psi

Strength Activity Index with Portland Cement = (A / B) x 100

7 DAY STRENGTH ACTIVITY INDEX = 2618 / 4686 x 100 = 56

28 DAY STRENGTH ACTIVITY INDEX = 4017 / 6248 x 100 = 64

WATER REQUIREMENT

Test Method ASTM C-311 sec 29

Note: Water requirement is calculated from the percentage of mix water determined in the Pozzolanic Index Test above.

Y = water required for test mix, ml
X = water required for control mix, 242 ml

WATER REQUIREMENT = Y/X x 100 = 262 / 242 x 100 = 108

Figure B.3: ASTM C109 for Volcanic Ash Sample 09-0808

TEST OF FLY ASH Specification ASTM C-618 Lab No. 09- 0808

EFFECTIVENESS IN CONTROLLING ALKALI SILICA-REACTIONS

Test Method ASTM C-311 sec. 30 & C-441

Operator: DD/DZ DATE: 12 / 22 / 09

Mix: Cement is Monarch I/II (08-1042)	Control	Test
Cement, (0.55% Alkali) - gm	400	340
Fly Ash - gm	0	60*
Pyrex Glass - gm	900	900
Water, distilled- ml...........	188	200
Flow (25 drops, 100-115%) - % .	109	112.5

Time: 11:20 Temp 71 °F R.H. 48 %

TRAIL FLOWS Water	Flow
C 191	121.5
188	109
T 188	68
T 200	112.5

*15% by wt. of cement + ash (see C-311 Appendix XI.4)

CANNOT BE STARTED ON MONDAYS (Read on day 14 but out of oven an day 13)

Cure: **DATES**

(✓) Remove from molds & measure @ 24 +- 2hr @ 73.4 +- 3°F 12-23-09

(✓) Place in container with 500ml water & in oven @ 100 +- 3°F 12-23-09

(✓) Remove from oven 16hr before 14 day measure 1-4-09

(✓) Measure length @ 14 days @ 73.4 +- 3°F 1-5-09

Test: Length of Specimens

Mix	CONTROL			TEST		
Specimen No	1	2	3	1	2	3
Final @ 14 days (in.)	0.0207	0.0138	-0.0038	-0.0013	0.0170	0.0143
** Initial @ 1 day (in.)	-0.0028	-0.0073	-0.0300	-0.0131	0.0052	0.0043
Increase (F-I) (in.)	0.0235	0.0211	0.0262	0.0118	0.0118	0.0100
Increase (avg) (in.)	0.0236		(E_C)	0.0112		(E_T)

** Effective gage length = 10"

Expansion Of Test as % of Control, % = (0.0112 E_T / 0.0236 E_C) x 100

Expansion Of Test as % of Control Mixture @ 14 DAYS = 47

Figure B.4: ASTM C618 ASR Mitigation for Volcanic Ash Sample 09-0808

TEST OF FLY ASH Specification ASTM C-618 Lab No. 09-0808

SOUNDNESS

Test Method ASTM C-311 sec. 22 and C-151

Mix:

Cement (Monarch I/II 08-1042) - gm ..	520
Fly Ash (Test Sample) - gm	130
Water (Distilled) - ml (%)	( )
Normal Consistency Penetration - mm ..	
Number of specimens	1
Date / Time	/
Lab temp. & R.H.	°F %
Mix by	

Test:

Length of Specimens - in. (effective gage length of 10")

Specimen No :

Final length .... 0.

Initial length ...... 0.

Difference .... 0.

AUTOCLAVE EXPANSION,% ______ % =(diff/10)x100

NC Mix Water (%)	mm (ML)
20.0	130
20.3	132
20.6	134
20.9	136
21.2	138
21.5	140
21.8	142
22.2	144
22.5	146
22.8	148
23.1	150
23.4	152
23.7	154
24.0	156
24.3	158
24.6	160
24.9	162
25.2	164

INCREASE OF DRYING SHRINKAGE OF MORTAR BARS

Test Method ASTM C-311 sec. 19 - 21 & C-157

Mix:

	Control	Test
Cement (Monarch I/II 08-1042) - gm	500	500
Fly Ash (Test sample) - gm	none	125
Sand (Standard -Graded C109) - gm	1375	1250
Water (distilled) - ml	232	252
Flow (25 drops, 100-115%)	106	107
No. of specimens	3	3
Date / Time	12-10-09 12:30	12:55
Lab Temp & R.H.	71 °F & 48 %R.H.	
Mixed by	D.A. / D.Z.	

Cure:

Moist cure (1 day in mold + 6 days out of mold on rack in moist cabinet) 7 days

Measure INITIAL length at 7 days and place in environmental cabinet 12-17-09

Air storage (in Russells environmental cabinet) for 28 days.

Measure FINAL length at 35 days.............................. 1-14-10

Measure:

Specimen	CONTROL 1	2	3	TEST 1	2	3
length @ 7da (L_i)	0.0040	0.0028	-0.0160	0.0069	-0.0227	-0.0240
length @ 35da (L_d)	-0.0033	-0.0040	-0.0227	-0.0004	-0.0297	-0.0313
drying shrink. (S)*	0.0073	0.0068	0.0067	0.0073	0.0070	0.0073

average of 3 (S_C) = 0.069 (S_T) = 0.072

* $S = [(L_i - L_d) \times 100]/10$

INCREASE IN DRYING SHRINKAGE (S_i) % = $S_t - S_c$ = 0.003

NOTE: The environmental cabinet was broken down the last 7 days of the 28 day test cycle,

DA

Figure B.5: ASTM C157 Results for Volcanic Ash Sample 09-0808

Specification ASTM C-618 TEST OF FLY ASH Lab No. 09-0808 0809

INCREASE OF DRYING SHRINKAGE OF MORTAR BARS / **RUSSELLS CABINET SCHEDULE**

Test Method ASTM C-311 sec. 19 - 21 & C-157
Temp C and R. H. % columns are posted from the cabinets chart reading
Record data twice daily around 10am and 3pm except Evaporation Rate which is am only

Date	am/pm	Temp C (23 ± 1.7)	R. H. % (50 ± 4)	Remarks	Beaker Wt gm	Evaporation Rate (13 ± 5 gm in 24 h) [or in 1 day]	Psychrometer R. H. %
ASTM Spec		21.3 – 24.7	46 – 54			8 – 18	
12-17	am	—	—		517		—
	pm	24.0	47.9				53
12-18	am	24.0	50.0		504	13	53
	pm	24.0	48.9				53
12-21	am	24.0	50.9		465	39 ÷ 3 = 13	53
	pm	24.0	48.9	Refill	511		53
12-22	am	24.0	49.9		500	11	53
	pm	24.0	50.0				53
12-23	am	24.0	50.9		489	11	53
	pm	24.0	50.9				53
12-24	am	24.0	48.9		477	12	53
	pm	24.0	50.9	REFILL	528		53
12-25	am						
	pm	←		HOLIDAY			→
12-28	am	23.9	49.9		514	14 ÷ 4 = 3.5*	53
	pm	24.0	51.9	REFILL	523 (*STORM SHUT POWER OFF ON 12-24)		53
12-29	am	24.0	48.8		506	17	53
	pm	24.2	51.9				53
12-30	am	23.9	48.8		491	15	53
	pm	—	—				—
12-31	am	24.0	48.9		477	14	53
	pm	24.0	51.0	REFILL	515		53
1-1	am						
	pm	←		HOLIDAY			→
1-4	am	24.0	49.8		457	58 ÷ 4 = 14	53
	pm	23.9	47.9	Refill	530		53
1-5	am	24.0	48.9		516	14	53
	pm	23.9	48.9				53
1-6	am	23.9	48.9		500	16	53
	pm	24.0	49.8				53
1-7	am	24.0	47.9		487	13	53
	pm	23.9	50.8				53
1-8	am	23.8	77.6		474	13	74
	pm			Refill	522		
1-11	am						
	pm						
1-12	am						
	pm						
1-13	am						
	pm						
1-14	am						
	pm						
	am						
	pm						
	am						
	pm						

Rev. 12/03

Figure B.6: ASTM C157 Data Sheet for Volcanic Ash Sample 09-0808

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Report of sample of FLY ASH - Class:______(C/F)

VOLCANIC ASH Laboratory No 09-0809

WORKSHEET FOR COMPLETE TESTING OF FLYASH. 2007 SMS 2004, ASTM C-618

Date Rep'td.______

Date Rec'd. 12-2-09

Specification No.______ Quantity______

Source of material______

Sample from______

Submitted by HEATHER McLOOD

Identification marks______ Field Lab No______

Project NO.______

Type of construction RESEARCH

Contractor______

SUMMARY OF PHYSICAL TESTS			ASTM C-618 Specifications
Fineness-No.325 wet-sieve (% retained)	21.4	[1	34 max
Strength Activity Index -			
With portland cement @ 7 days (% of control)	63	[0 (e)	75 min
With portland cement @28 days (% of control)	73	[0 (e)	75 min
Water requirement (% of control)	107	[0	105 max
Soundness-autoclave expansion (%)	—	[2	0.8 max
Density (g/cm^3)	2.33	[2	none
Multiple Factor-loss on ignition x 325 fineness (%)		[1 (a)	255 max
Increase of Drying Shrinkage of mortar bars @28 days (%)	0.006	[3	0.03 max

Effectiveness in Controlling Alkali Silica-Reactions

Expansion of Test as % of Control @ 14 Days	27	[0	120 max
Fly Ash as % of total cem + ash	15 %		
Alkali content of cement used	0.55 %		

Cement used and Lab Number: . . . . Monarch I/II 08-1042

Number of decimal places to report = [N

NOTE: ASTM C-618 covers Class C and F fly ashes.
(a) specified for Class F only.
(e) meeting the 7 or 28 day indicates specification compliance.

120 max. for use in Concrete, and Concrete Pipe.

Figure B.7: Summary of ASTM C618 for Volcanic Ash Sample 09-0809

TEST OF FLY ASH Specification ASTM C-618 Lab No. 09-0809

DENSITY

Test Method ASTM C-311 sec. 17 & C-188
Flask No. 2

Reference Flask - start 0.0
finish 0.0
change 0.0

Final Flask Reading (ml) 22.0
Correction for Ref. change ... 0.0
Initial Flask Reading (ml) ... 0.5
Volume Displaced (ml) * 21.5
Sample Weight (gm) 50.00

Density (gm/cm³) = 50 / volume displaced = 2.33

* **Final - Initial**

ml density	ml density	ml density	ml density	ml density
17.5 = 2.86	18.3 = 2.73	19.1 = 2.62	19.9 = 2.51	20.7 = 2.42
17.6 = 2.84	18.4 = 2.72	19.2 = 2.60	20.0 = 2.50	20.8 = 2.40
17.7 = 2.82	18.5 = 2.70	19.3 = 2.59	20.1 = 2.49	20.9 = 2.39
17.8 = 2.81	18.6 = 2.69	19.4 = 2.58	20.2 = 2.48	21.0 = 2.38
17.9 = 2.79	18.7 = 2.67	19.5 = 2.56	20.3 = 2.46	21.1 = 2.37
18.0 = 2.78	18.8 = 2.66	19.6 = 2.55	20.4 = 2.45	21.2 = 2.36
18.1 = 2.76	18.9 = 2.65	19.7 = 2.54	20.5 = 2.44	21.3 = 2.35
18.2 = 2.75	19.0 = 2.63	19.8 = 2.53	20.6 = 2.43	21.4 = 2.34

FINENESS BY #325 SIEVE

Test Method ASTM C-311 sec. 19.1 & C-430

Sieve Correction Factor .... (-0.54)
Sample Size (gm) 1.0000
Amount Retained (gm) 0.2198
Fineness = (0.2198 x 100) + (-0.54) = 21.44 % **Retained**

Fineness = (gm. ret x 100) + sieve correction factor

MULTIPLE FACTOR

Specification ASTM C-618 Table 2a
Note: The multiple factor is calculated as the product of the loss on ignition and the fineness amount retained on the # 325 sieve.
L = loss on ignition = ______ %
F = fineness, % ret. = 21.44 %

MULTIPLE FACTOR = L X F = ______ x 21.44 = ______

Figure B.8: ASTM C430 for Volcanic Ash Sample 09-0809

TEST OF FLY ASH Specification ASTM C-618 Lab No. 09-809

STRENGTH ACTIVITY INDEX WITH PORTLAND CEMENT

Test Method ASTM C-311 sec. 25 - 28 and C-109

Mix:

	Control	Test
Cement (**Monarch I/II** 08-1042) - gm	500	400
Fly Ash (Test sample) - gm	none	100
Sand (Standard -Graded C109) - gm	1375	1375
Water (distilled) - ml	242	258 262
Flow % (25 drops, test +/- 5 of control)	128.5	124.5 131.5
No. of specimens	6	6
Date / Time	12-7-09 7:30	9:10 9:00

Lab Temp & R.H. .... 71 °F & 57 %R.H.
Mixed by ....

Cure: Dates

Moist Cure all specimens, in molds, for 1 day until ... 12-8-09
Then in **Lime Saturated Water Cure** (C-109)
Test half the specimens @ 7 days age 12-14-09

Test the remaining specimens @ 28 days age 1-4-10

Test: Compressive Strength (lbs)

	7 Day Control (B)	7 Day Test (A)	28 Day Control (B)	28 Day Test (A)
(1)	18871	11591	24581	19227
(2)	18462	11701	25385	17653
(3)	18954	12357	25007	17900
Avg (psi)*	4686	2971	6248	4565

* (1+2+3)/12= avg psi

Strength Activity Index with Portland Cement = (A / B) x 100

7 DAY STRENGTH ACTIVITY INDEX = 2971 / 4686 x 100 = 63

28 DAY STRENGTH ACTIVITY INDEX = 4565 / 6248 x 100 = 73

WATER REQUIREMENT

Test Method ASTM C-311 sec 29

Note: Water requirement is calculated from the percentage of mix water determined in the Pozzolanic Index Test above.

Y = water required for test mix, ml
X = water required for control mix, 242 ml

WATER REQUIREMENT = Y/X x 100 = 258 / 242 x 100 = 107

Figure B.9: ASTM C109 for Volcanic Ash Sample 09-0809

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TEST OF FLY ASH Specification ASTM C-618 Lab No. 09-0809

EFFECTIVENESS IN CONTROLLING ALKALI SILICA-REACTIONS

Test Method ASTM C-311 sec. 30 & C-441

Operator: DH DATE: 12 / 22 / 09

Mix: Cement is Monarch I/II (~~08-1042~~ 09-2991)

	Control	Test
Cement, (~~0.55%~~ 0.44 Alkali) - gm	400	340
Fly Ash - gm	0	60*
Pyrex Glass - gm	900	900
Water, distilled- ml.......171..	188	208
Flow (25 drops, 100-115%) - % .	109	105.5

Time: 7:30 Temp 71 °F R.H. 48 %

TRAIL FLOWS Water	Flow
200	88.5
204	90.5
208	105.5

*15% by wt. of cement + ash (see C-311 Appendix XI.4)

CANNOT BE STARTED ON MONDAYS (Read on day 14 but out of oven an day 13)

Cure: **DATES**

(✓) Remove from molds & measure @ 24 +- 2hr @ 73.4 +- 3°F 12-23-09

(✓) Place in container with 500ml water & in oven @ 100 +- 3°F 12-23-09

(✓) Remove from oven 16hr before 14 day measure 1-4-09

(✓) Measure length @ 14 days @ 73.4 +- 3°F 1-5-09

Test: Length of Specimens

Mix	CONTROL			TEST		
Specimen No	1	2	3	1	2	3
Final @ 14 days (in.)	0.0207	0.0138	-0.0038	0.0181	0.0143	-0.0325
** Initial @ 1 day (in.)	-0.0028	-0.0073	-0.0300	0.0127	0.0070	-0.0388
Increase (F-I) (in.)	0.0235	0.0211	0.0262	0.0054	0.0073	0.0063
Increase (avg) (in.)	0.0236		(E_C)	0.0063		(E_T)

** Effective gage length = 10"

Expansion Of Test as % of Control, % = (0.0063 E_T / 0.0236 E_C) x 100

Expansion Of Test as % of Control Mixture @ 14 DAYS = 27

NOTE:

New reference cement was used on the test for 09-0809. The total alkali is 0.44, compared to 0.55 for the Control, and the test for 09-808.

Figure B.10: ASTM C618 ASR Mitigation for Volcanic Ash Sample 09-0809

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TEST OF FLY ASH Specification ASTM C-618 Lab No. 09-0809

SOUNDNESS

Test Method ASTM C-311 sec. 22 and C-151

Mix:

Cement (**Monarch I/II** 08-1042) - gm .. 520
Fly Ash (Test Sample) - gm 130
Water (Distilled) - ml (%) .... ( )
Normal Consistency Penetration - mm ..
Number of specimens 1
Date / Time .... /
Lab temp. & R.H. .... °F %
Mix by ....

Test:
Length of Specimens - in. (effective gage length of 10")
Specimen No :
Final length .... 0.
Initial length ...... 0.
Difference .... 0.
AUTOCLAVE EXPANSION,% % =(diff/10)x100

NC Mix Water (%)	mm	(ML)
20.0		130
20.3		132
20.6		134
20.9		136
21.2		138
21.5		140
21.8		142
22.2		144
22.5		146
22.8		148
23.1		150
23.4		152
23.7		154
24.0		156
24.3		158
24.6		160
24.9		162
25.2		164

INCREASE OF DRYING SHRINKAGE OF MORTAR BARS

Test Method ASTM C-311 sec. 19 - 21 & C-157

Mix:

	Control	Test
Cement (**Monarch I/II** 08-1042) - gm	500	500
Fly Ash (Test sample) - gm	none	125
Sand (Standard -Graded C109) - gm	1375	1250
Water (distilled) - ml	232	248
Flow (25 drops, 100-115%)	106	102
No. of specimens	3	3
Date / Time	12-10-09 12:30	1:15
Lab Temp & R.H.	71 °F & 48 %R.H.	
Mixed by	D.H	

Cure:
Moist cure (1 day in mold + 6 days out of mold on rack in moist cabinet) 7 days
Measure INITIAL length at 7 days and place in environmental cabinet 12-17-09
Air storage (in Russells environmental cabinet) for 28 days.
Measure FINAL length at 35 days............................. 1-14-10

Measure:

Specimen	CONTROL 1	CONTROL 2	CONTROL 3	TEST 1	TEST 2	TEST 3
length @ 7da (L_i)	0.0040	0.0028	-0.0160	-0.0030	-0.0009	-0.0474
length @ 35da (L_d)	-0.0033	-0.0040	-0.0227	-0.0108	-0.0084	-0.0547
drying shrink. (S)*	0.073	0.068	0.067	0.078	0.075	0.073

average of 3 (S_C) = 0.069 (S_T) = 0.075

* $S = [(L_i - L_d) \times 100]/10$

INCREASE IN DRYING SHRINKAGE (S_i) % = $S_t - S_c$ = 0.006

NOTE: The environmental cabinet was broken down for the last 7 days of the 28 day test cycle.
DH

Figure B.11: ASTM C157 Results for Volcanic Ash Sample 09-0809

Appendix C: Stage 3 ASTM C157 Concrete Length Change Results

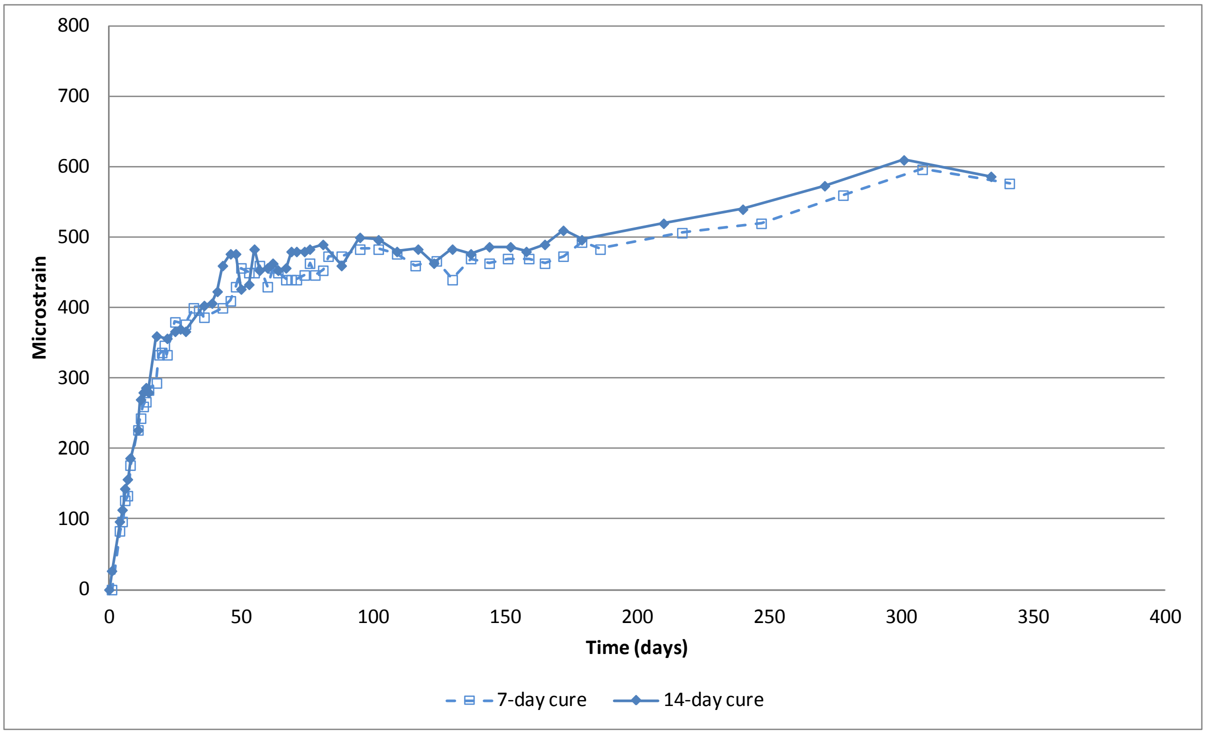

Figure C.1: ASTM C157 Batch 1 Limestone 1 with 0% Volcanic Ash

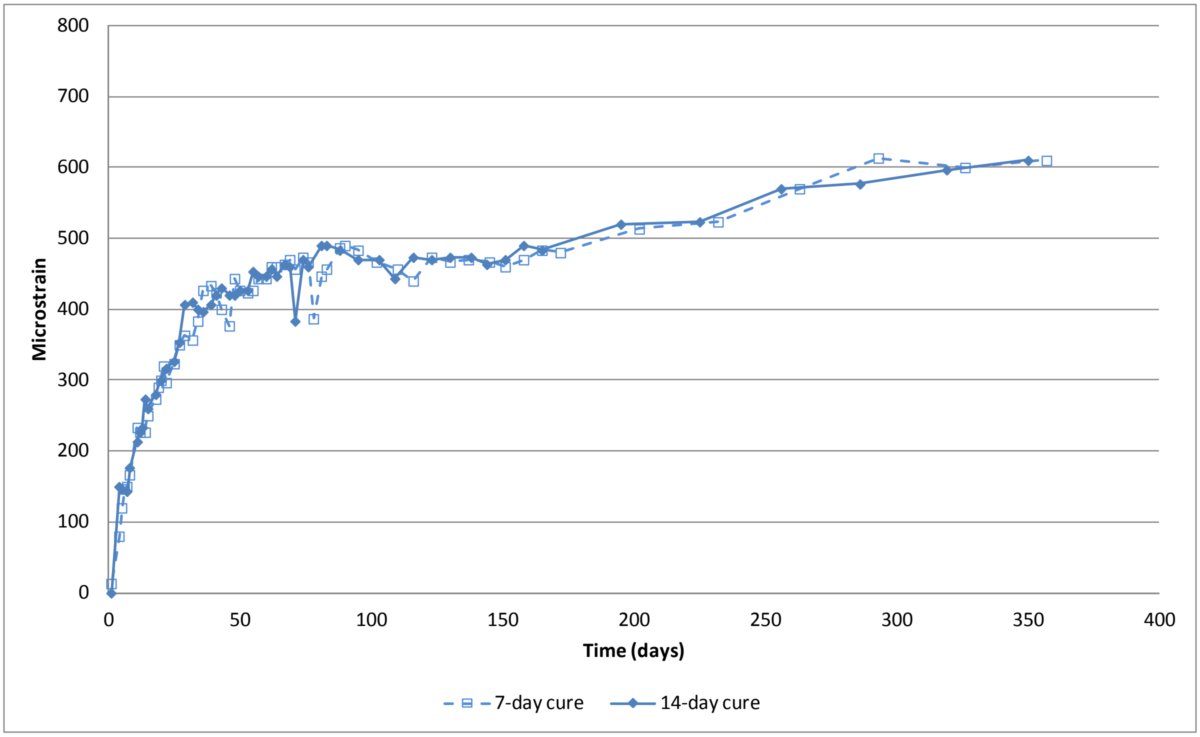

Figure C.2: ASTM C157 Batch 5 TMA 1 with 20% Volcanic Ash

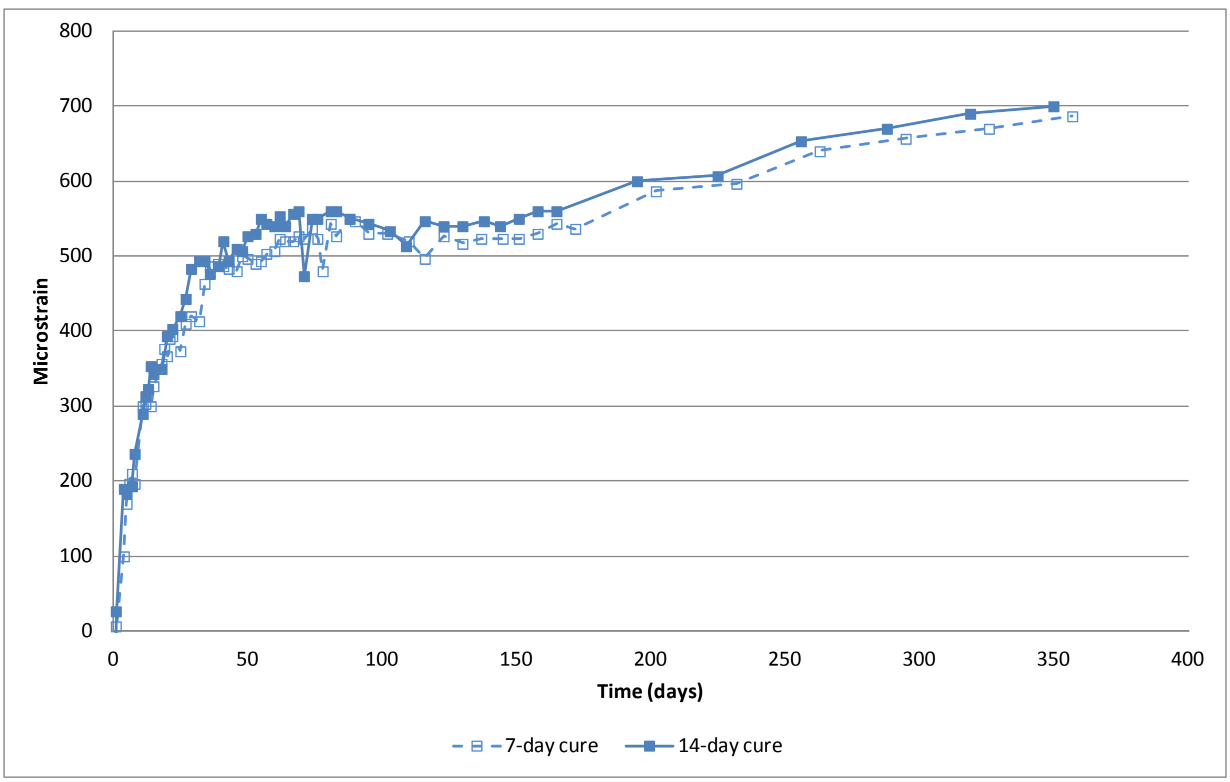

Figure C.3: ASTM C157 Batch 6 TMA 1 with 40% Volcanic Ash

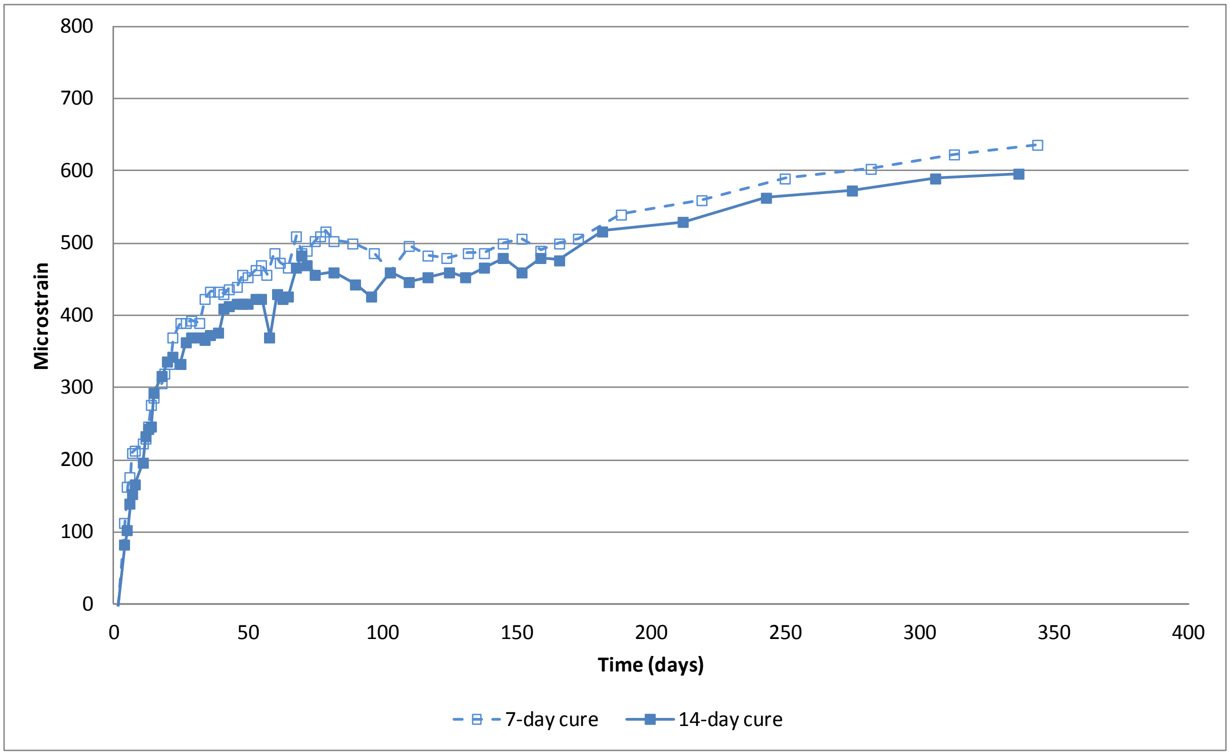

Figure C.4: ASTM C157 Batch 7 TMA 2 with 20% Volcanic Ash

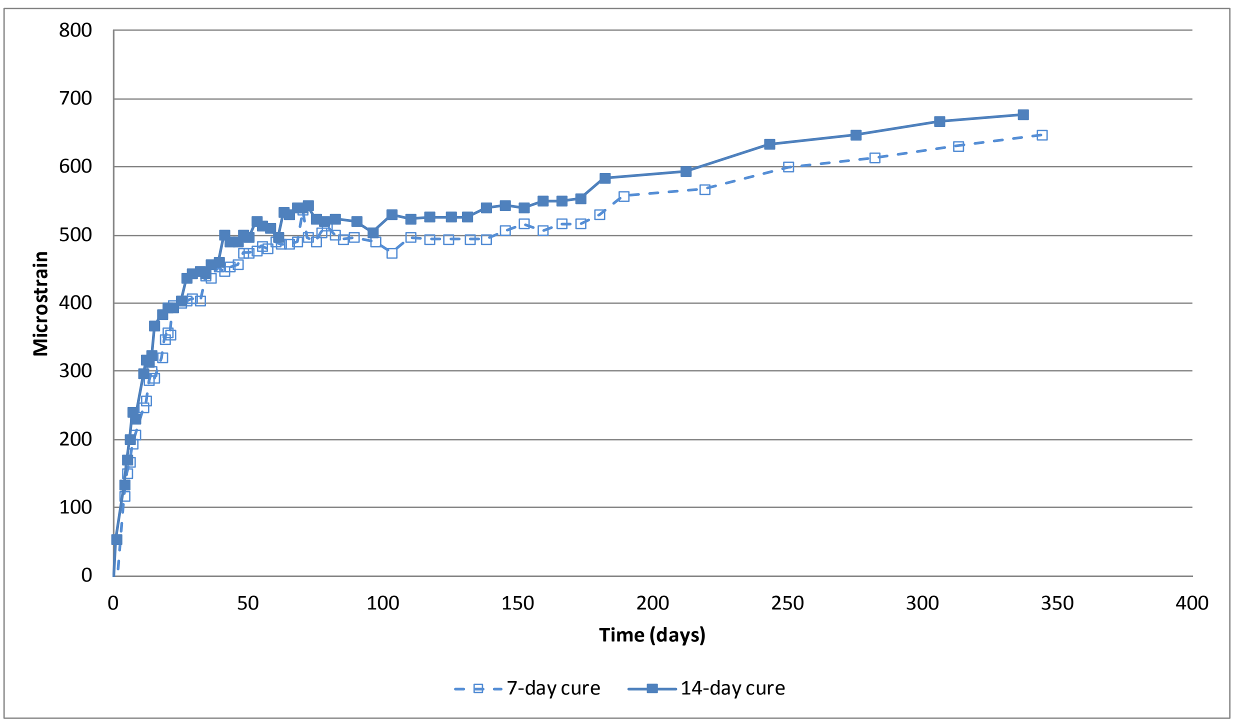

Figure C.5: ASTM C157 Batch 8 TMA 2 with 40% Volcanic Ash

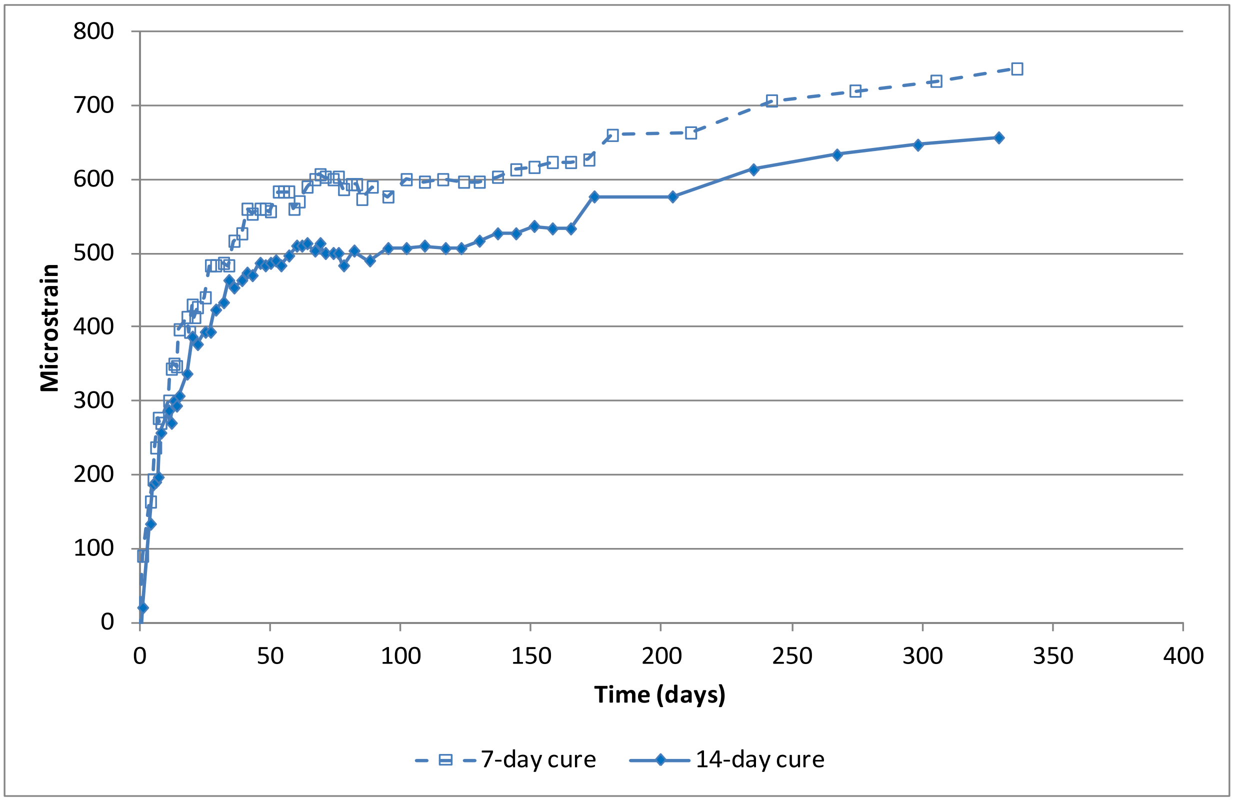

Figure C.6: ASTM C157 Batch 9 TMA 1 with 0% Volcanic Ash

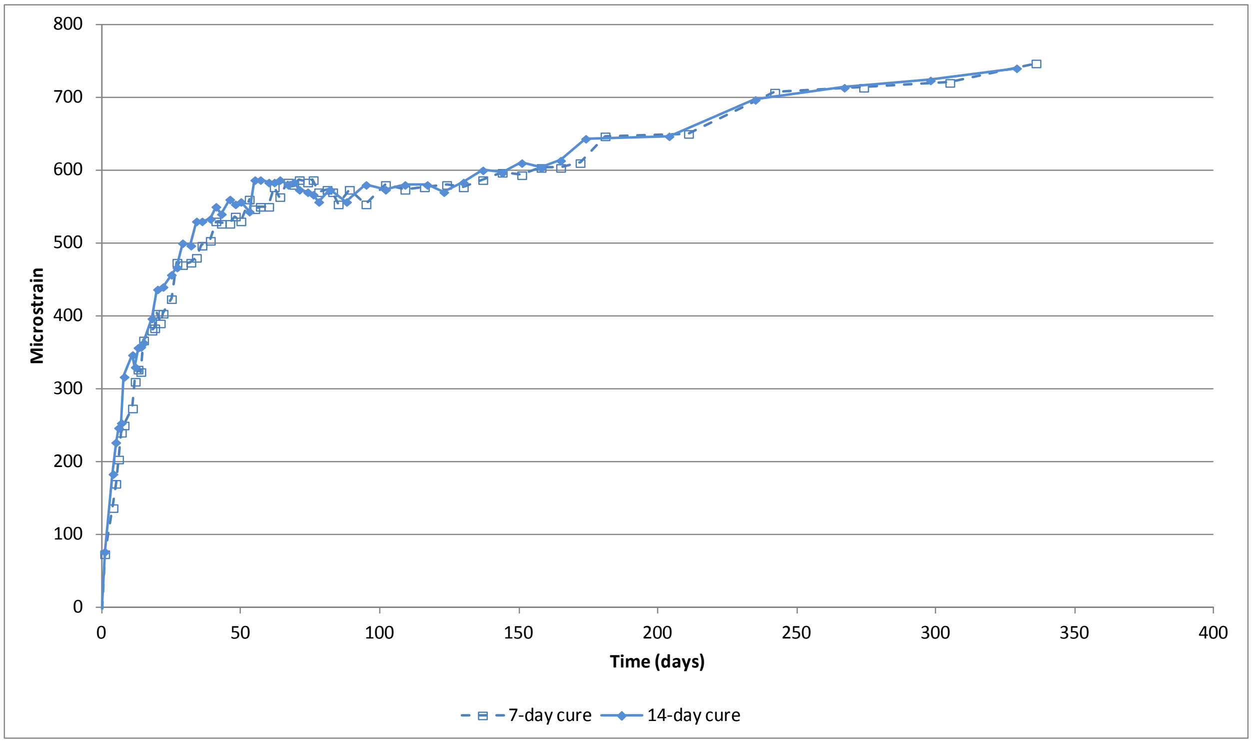

Figure C.7: ASTM C157 Batch 10 TMA 2 with 20% Volcanic Ash

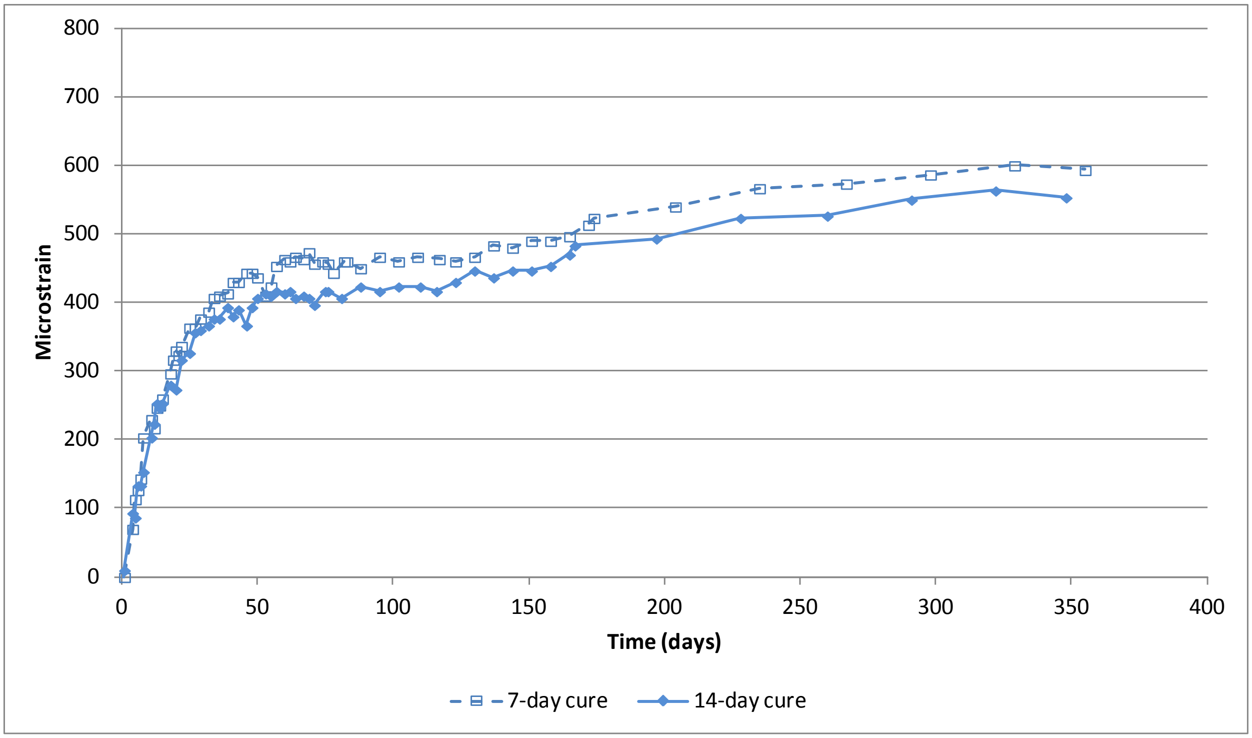

Figure C.8: ASTM C157 Batch 11 Limestone 2 with 20% Volcanic Ash

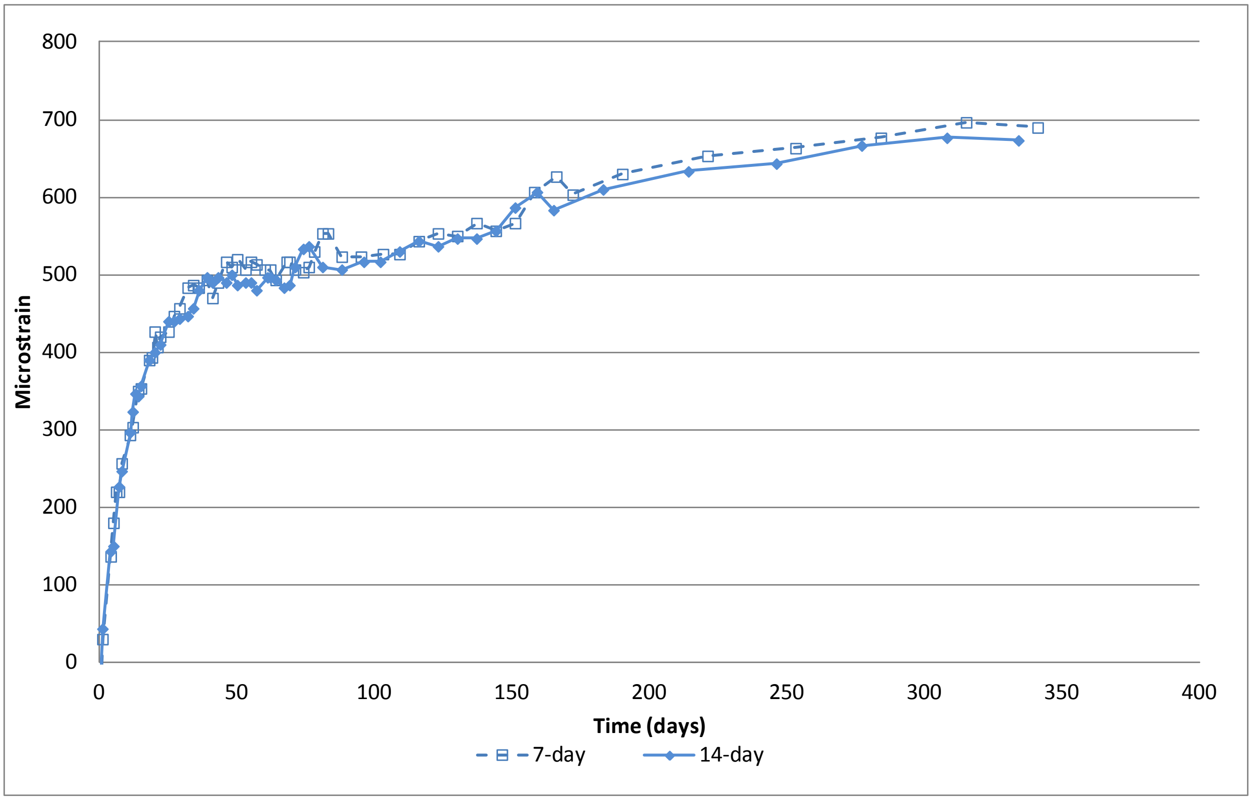

Figure C.9: ASTM C157 Batch 12 Limestone 2 with 40% Volcanic Ash

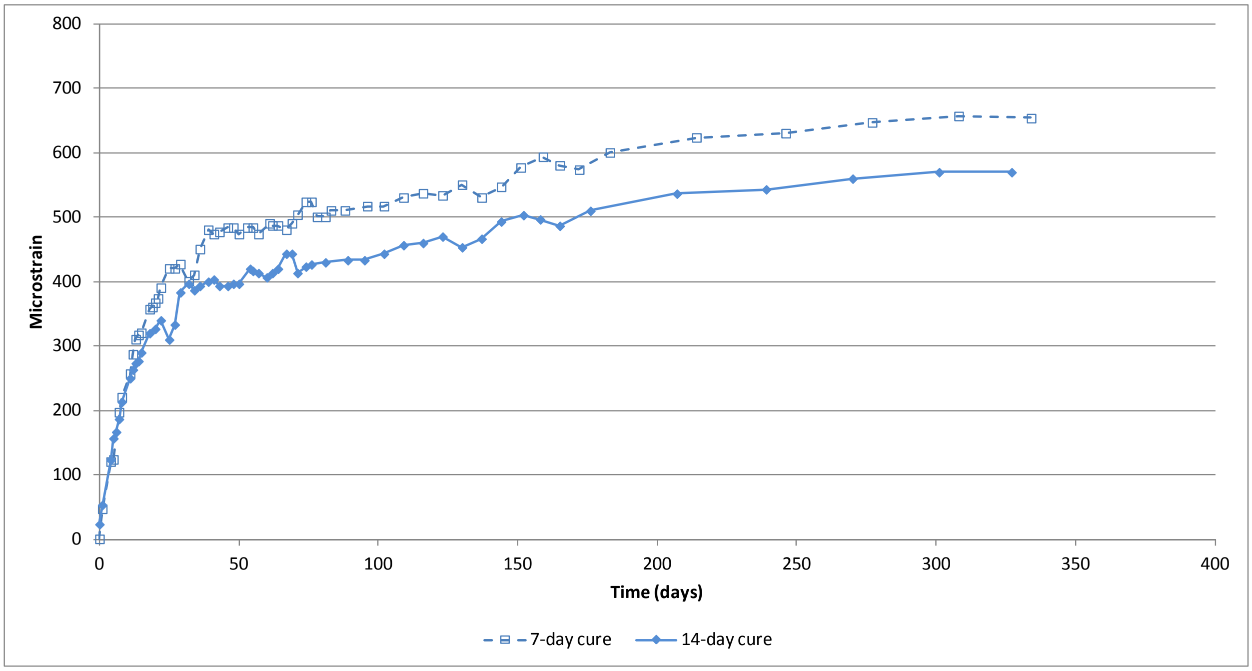

Figure C.10: ASTM C157 Batch 13 Limestone 2 with 0% Volcanic Ash

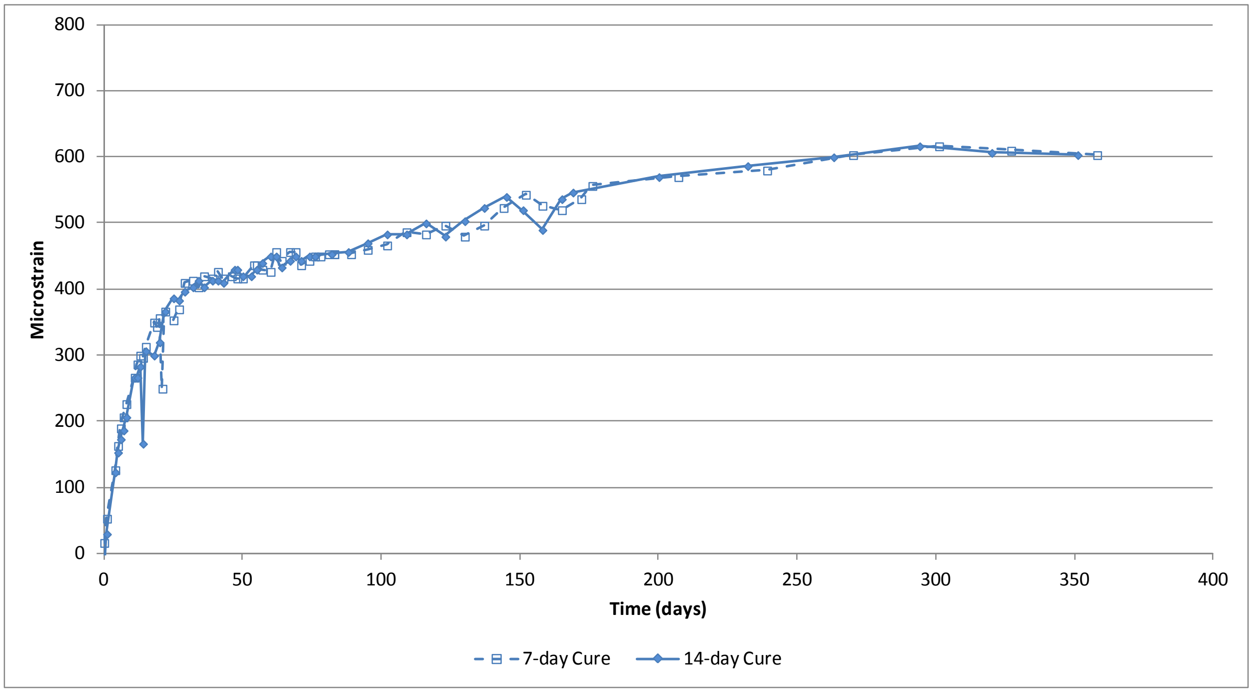

Figure C.11: ASTM C157 Batch 14 Limestone 2 with 40% Volcanic Ash

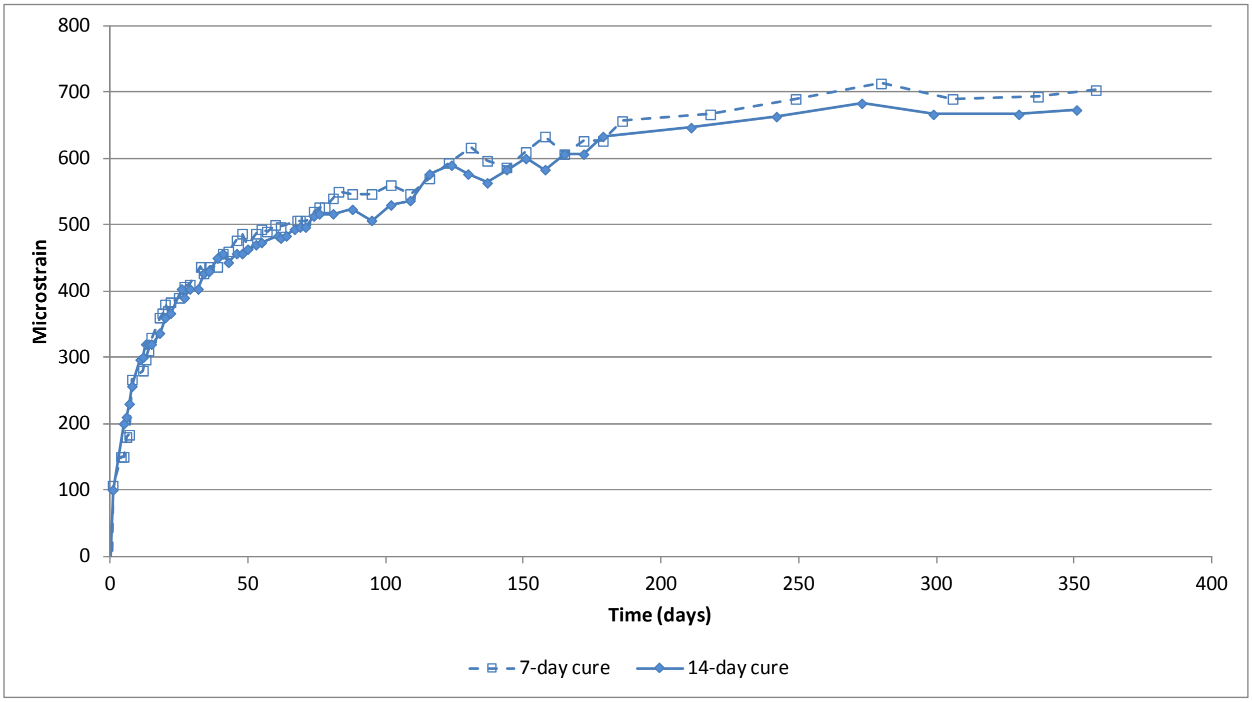

Figure C.12: ASTM C157 Batch 15 Limestone 2 with 10% Volcanic Ash

Appendix D: KTMR-23 Wetting and Drying Test Results

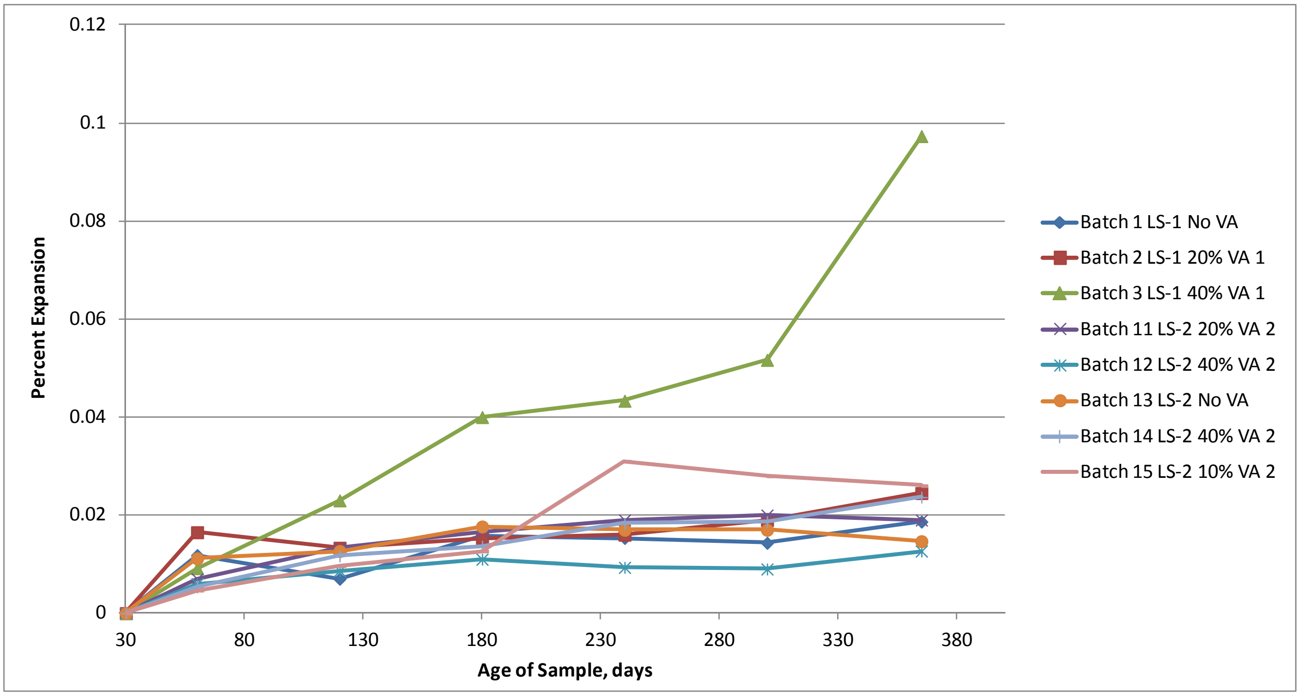

Figure D.1: KTMR-23 Percent Expansion for Batches Containing Limestone

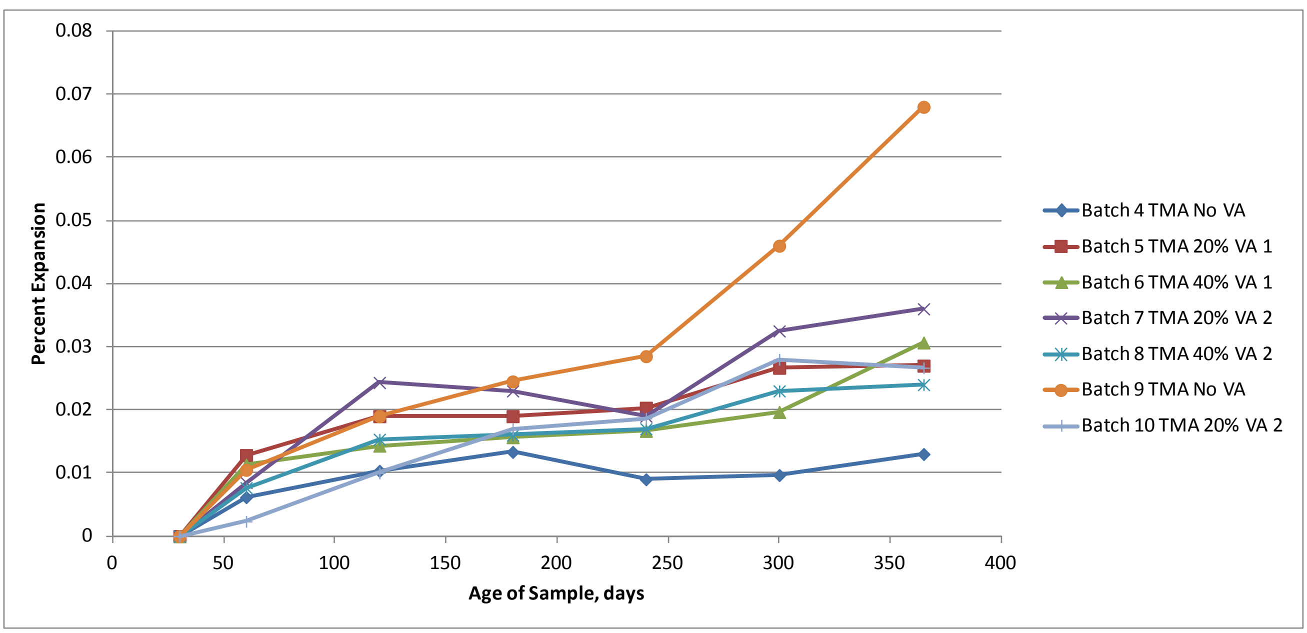

Figure D.2: KTMR-23 Percent Expansion for Batches Containing TMA

Appendix E: Stage 3 ASTM C232 Bleed Test Results

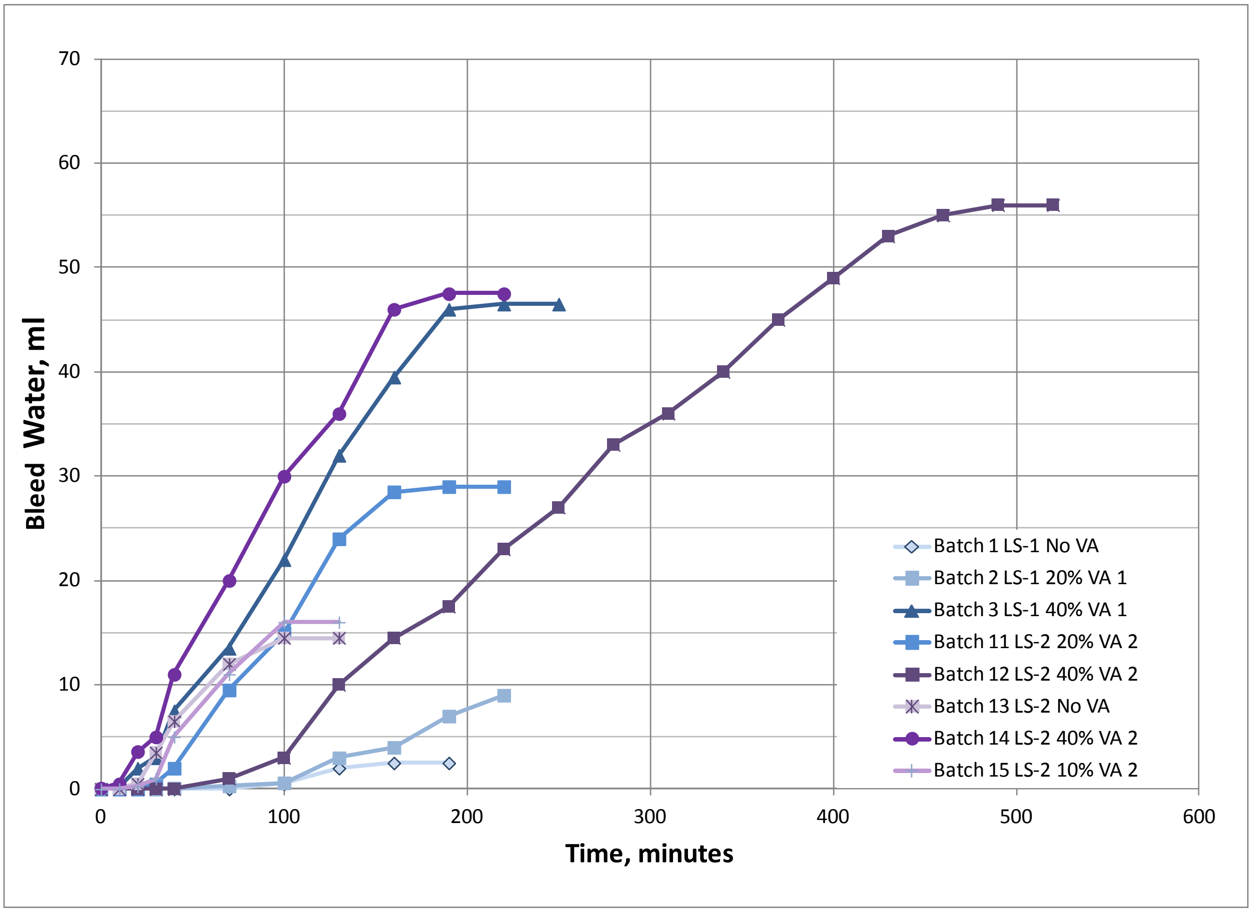

Figure E.1: ASTM C232 Bleed Test for Batches Containing Limestone

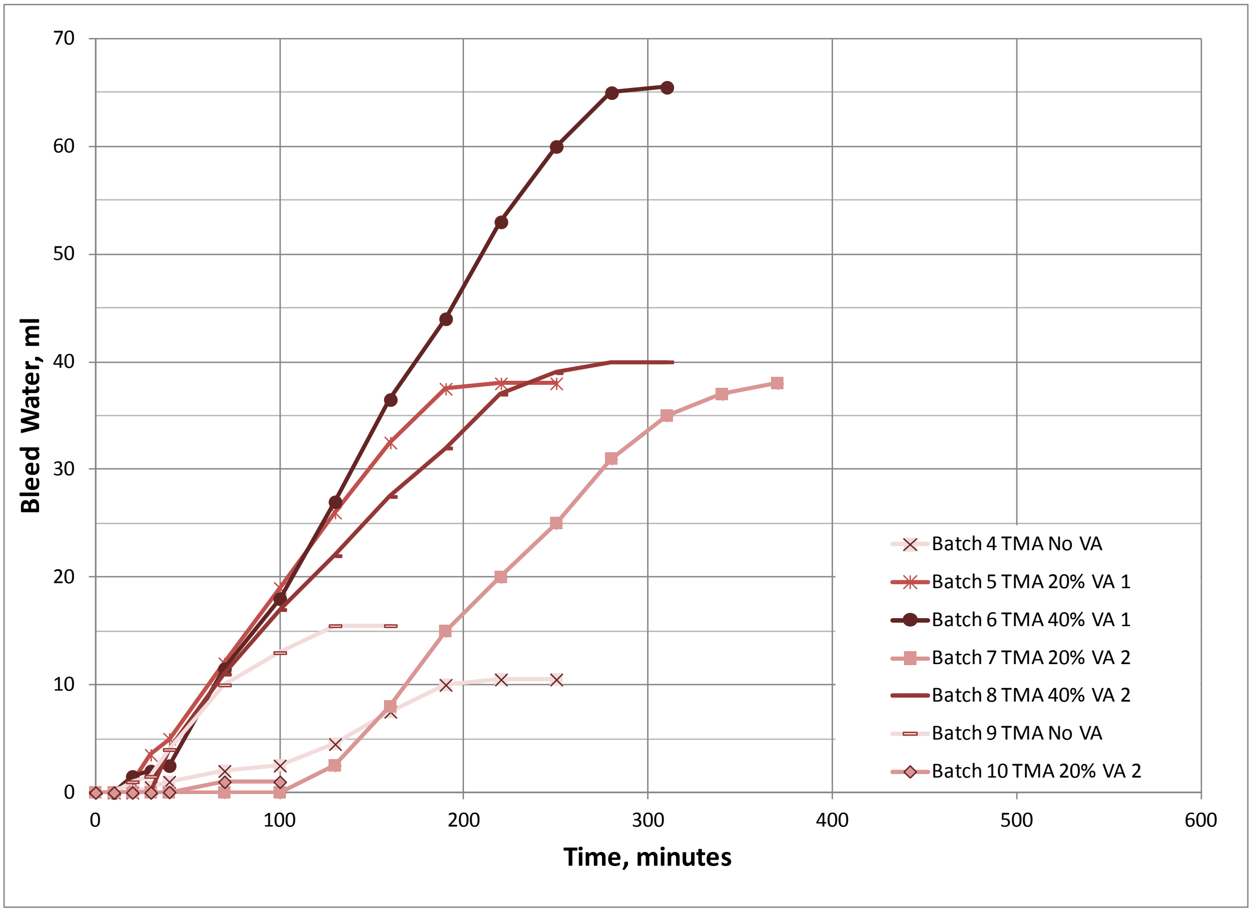

Figure E.2: ASTM C232 Bleed Test for Batches Containing TMA


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