Abstract

The Kansas Department of Transportation (KDOT) has a history of using tests such as concrete strength, permeability, and air void structure as design and acceptance criteria on concrete paving and bridge deck projects. In 2012, the KDOT Concrete Research group concluded a study on testing the length change of hardened concrete according to ASTM C157 (2008), commonly referred to as free shrinkage. This free shrinkage test was reviewed as a possible design or acceptance test for construction projects, primarily relating to bridge decks where even minimal cracking is detrimental. ASTM C157 has been successfully implemented at KDOT's central testing laboratory should future testing be required. However, the equipment required and the conditions under which this test is conducted would indicate that this test would have to be conducted by private laboratories and not by Kansas contractors. This may preclude this test from being incorporated as a design or acceptance requirement.

Acknowledgements

Special thanks are extended to Kansas Department of Transportation (KDOT) Research personnel Rodney Montney, Heather McLeod, and Jennifer Distlehorst for their guidance and support during the course of the study and for their review of this report. Thanks are extended to Concrete Research and Research Development Technicians for their efforts in training personnel and completing the testing and data collection.

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Chapter 1: Introduction

1.1 Background

In 2012, the Kansas Department of Transportation (KDOT) Concrete Research group concluded a study on testing the length change of hardened concrete according to ASTM C157 (2008), commonly referred to as free shrinkage. KDOT began this project to determine if an acceptance specification should be developed for KDOT's concrete construction projects. KDOT has a history of using tests such as concrete strength, permeability, and air void structure as design acceptance criteria on concrete paving and bridge deck projects. This free shrinkage test was reviewed as a possible design or acceptance test for construction projects, primarily relating to bridge decks where even minimal cracking is detrimental.

ASTM C157 measures the strain in concrete due to shrinkage. With this test, the effects of different mix designs on free shrinkage can be determined. To this point, ASTM C157 has been implemented to evaluate mixtures containing various amounts of volcanic ash as a supplementary cementitious material (SCM) substituting portland cement in laboratory mixtures as part of an ongoing research project investigating Kansas sources of volcanic ash. Free shrinkage measurements are also useful in designing mixes for low-cracking high-performance concrete (LC-HPC) bridge decks and other design situations where excessive shrinkage and drying shrinkage cracking is detrimental to the performance of the structure. KDOT research has also developed methods for casting ASTM C157 specimens in the field.

1.2 Problem Statement

Kansas finds itself with harsh winters that require frequent use of de-icing salts on the roadways. Considering the significant number of freeze-thaw cycles that Kansas undergoes, it is critical to the long-term durability of a concrete structure that the permeability of said concrete is kept under control. Permeability, however, is not simply a function of concrete composition, but also whether or not it is cracked. With this in mind, by reducing and controlling the shrinkage in concrete, thereby controlling the shrinkage cracking, permeability can better be kept under control (Deshpande, Darwin, & Browning, 2007).

1.3 Objectives

The objectives of this study are to successfully implement ASTM C157 at KDOT's central materials testing laboratory in Topeka, KS. This will include obtaining the proper equipment, training personnel on both sample creation and preparation, and accurate testing of samples.

1.4 Scope

This report includes testing of 15 laboratory mixes and concrete from seven field projects for a total of 23 sets of prisms. Six prisms were cast for each mix, with three specimens cured for 7 days, and three cured for 14 days. Shrinkage measurements for each mix were taken for 1 year. See Section 2.2 for the testing schedule.

Chapter 2: Methodology

2.1 Facilities and Materials

2.1.1 Facilities and Procedure-Related Materials

Several ASTM procedures specify the facilities and materials. The required facilities include an environmentally controlled room or chamber (ASTM C511, 2009), lime-saturated curing tanks stored at 73±1 °F (ASTM C157, 2008), drying racks, and a temperature- and humidity-controlled room held at 73±3 °F and 50±4 % relative humidity (ASTM C157). Lime-saturated tanks in the moist room and the cement laboratory at the Materials and Research Center were used for this study. Procedure-related materials include 3 × 3 × 11 ¼-inch prism molds with gage studs (ASTM C157; KDOT, 2007, Special Provision 07-11004-R07 limits aggregate to 0–10% of 1-inch material), a tamping rod or external vibrating table (ASTM C192, 2007), and a comparator with reference bar (ASTM C490, 2010).

2.1.2 Sample Materials

The 15 laboratory mixes, Batches 1–15, consisted of different combinations of coarse aggregates and cement/supplementary cementitious materials (SCM) ratios (Table 2.1). Volcanic ash was the primary SCM added to Batches 1–15. The remaining batches listed are specimens that were cast on various bridge projects in the field. See Table 2.1.

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

The limestone coarse aggregate (designated LS-1) used in combination with the volcanic ash was a Class I limestone that met KDOT's 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 mixes were 50/50 CA/FA mixes. The total mixed aggregate (designated TMA-1) that was used was a sand/sand gravel from Klotz

Sand that met KDOT's MA-2 gradation. Both the LS-2 and TMA-2 designations indicate that the material was from a second sampling of the respective original material.

Table 2.1: Basic Mix Design Information

Batch/Lab No.	Coarse Aggregate	CF %	SCM	SCM %
1	LS-1 (50/50)	100	-	-
2	LS-1 (50/50)	80	Volcanic Ash, 09-0809	20
3	LS-1 (50/50)	60	Volcanic Ash, 09-0809	40
4	TMA-1	100	-	-
5	TMA-1	80	Volcanic Ash, 09-0809	20
6	TMA-1	60	Volcanic Ash, 09-0809	40
7	TMA-2	80	Volcanic Ash, 09-0808	20
8	TMA-2	60	Volcanic Ash, 09-0808	40
9	TMA-1	100	-	-
10	TMA-2	80	Volcanic Ash, 09-0808	20
11	LS-2 (50/50)	80	Volcanic Ash, 09-0808	20
12	LS-2 (50/50)	60	Volcanic Ash, 09-0808	40
13	LS-2 (50/50)	100	-	-
14	LS-2 (50/50)	60	Volcanic Ash, 09-0808	40
15	TMA-2	90	Volcanic Ash, 09-0808	10
09-3514	LS-1 (50/50)	100	-	-
10-0915	Light weight aggregate (31%)	65	Ground-granulated blast furnace slag (35%)	35
10-1012	Granite (50/50)	77	Silica Fume (4%); Class F Fly Ash (19%)	23
10-2203	Granite (60/40)	60	Silica Fume (5%); GGBFS (35%)	40
10-2995	Granite (60/40)	60	Silica Fume (5%); GGBFS (35%)	40
10-3463	Granite (60/40)	100	-	-
10-3529	Granite (60/40)	60	Silica Fume (5%); GGBFS (35%)	40
11-0849	Granite (60/40)	75	GGBFS (25%)	25

2.2 Methods

The procedure used for these tests is ASTM C157, "Standard Test Method for Length Change of Hardened Hydraulic-Cement Mortar and Concrete," with four minor exceptions. The first exception was that six prisms were cast instead of the required three in ASTM C157. This variation was used to evaluate the shrinkage for both the 7- and 14-day lime-saturated water curing periods. The other variations include the curing temperature, the length of time the samples were cured (7 and 14 days), and the frequency at which readings were taken, as described next.

The prisms were cast in 3 × 3 × 12-inch prism molds with gage studs. A vibrating table was used to consolidate the two lifts placed in each mold. Each lift was vibrated for 30 seconds before the second lift was added or before finishing was performed. For samples cast in the laboratory, 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 (as opposed to the 73±1 °F specified). An initial length reading was taken, and then the samples were returned to a lime-saturated solution and placed in the moist room for humidity (100%) and temperature control. For samples cast in the field, the samples were covered in saturated burlap and plastic and then placed in an insulated container to prevent moisture loss and temperature variation while the specimens were initially curing. At 23±½ hours, the specimens were then brought back to the laboratory to be removed from the molds. 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 and cured in lime-saturated water for 30 minutes, 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 on drying racks allowing sufficient air flow around the specimens in a temperature and humidity controlled room at 70±3 °F and 50±4 % relative humidity.

The final variation from ASTM C157 for the purposes of this study was the testing frequency after the samples were placed in dry storage. Due to a shift in testing frequency during the project, two time references are used. The first refers to the specimen age from the cast date. For the first 30 days (from cast date), a reading was taken every day of the week. After 30 days, a reading was taken three times a week, on Monday, Wednesday, and Friday, until specimens reached 90 days of age. After 90 days, a reading was taken once a week on Monday until an age of 180 days. For the remainder of the 365 days, a reading was taken on the first of each month with the final reading taken on the 365th day. Starting in 2011, the same schedule is followed; however, the time refers to the number of days of drying (i.e., samples were read every day for the first 30 days of drying; 36 and 43 days of age for the 7- and 14-day cures, respectively). See Tables 2.2 and 2.3, respectively. This scheduling change affected only one set of samples in this study, 11-0849, but was continued as standard practice for all subsequent shrinkage testing that was performed outside of this study until the summer of 2012, at which point testing reverted back to the original schedule based on age. 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 readings were taken in the same climate-controlled room in which the samples are kept for dry storage. 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 by the overall length of the prism.

Table 2.2: Testing Schedule Based on Sample Age

Sample Age, Days	Testing Frequency
1–30	5 days/week (M-F); Day 30
31–90	3 days/week (M,W,F); Day 90
91–180	1 day/week (M); Day 180
181–365	1 day/month (1st of month); Day 365

Table 2.3: Testing Schedule Based on Sample Drying Time

Drying Time (Age, 7/14 day samples), Days	Testing Frequency
1–30 (7/14–36/43)	5 days/week (M-F); Day 30
31–90 (37/44–96/103)	3 days/week (M,W,F); Day 90
91–180 (97/104–186/193)	1 day/week (M); Day 180
181–365 (187/194–371/378)	1 day/month (1st of month); Day 365

Chapter 3: Results and Conclusions

3.1 Test Results

Strain values were calculated for each set of prisms and micro-strain was plotted versus the time at which the reading was taken. The plots for each of the mixes are presented in the Appendix. Note that plots for Batches 2–4 are not presented as an initial reading was not taken for those prisms. Results indicate that strain values for the 7- and 14-day cure specimens are similar for specimens cast in the laboratory. Specimens cast in the field show a greater difference in strain between the two curing periods, with the specimens cured for 14 days exhibiting less strain. Also, it is noted that most of the field specimens contain SCMs other than volcanic ash, indicating that the SCMs may be responsible for the difference in strain vs. curing observed due to the slower property development of SCMs.

It has been concluded that ASTM C157 has been successfully implemented at KDOT’s central testing laboratory should future testing be required. It has also been concluded that the testing schedule based on the age of the sample is the preferred method, as it follows common practice of reporting a concrete test result at a given sample age. Further research should be completed to determine whether a performance-based acceptance specification for free shrinkage should be implemented at KDOT and how the use of SCMs might affect said specification. However, the equipment required and conditions under which this test is conducted would indicate that this test would have to be conducted by private laboratories and not Kansas contractors. This may preclude this test from being incorporated as a design or acceptance requirement.

References

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 C192 / C192M-07. (2007). *Standard practice for making and curing concrete test specimens in the laboratory*. West Conshohocken, PA: ASTM International. doi: 10.1520/C0192_C0192M-07, www.astm.org

ASTM C490 / C490M-10. (2010). *Standard practice for use of apparatus for the determination of length change of hardened cement paste, mortar, and concrete*. West Conshohocken, PA: ASTM International. doi: 10.1520/C0490_C0490M-10, www.astm.org

ASTM C511-09. (2009). *Standard specification for mixing rooms, moist cabinets, moist rooms, and water storage tanks used in the testing of hydraulic cements and concretes*. West Conshohocken, PA: ASTM International. doi: 10.1520/C0511-09, www.astm.org

Deshpande, S., Darwin, D., & Browning, J. (2007). *Evaluating free shrinkage of concrete for control of cracking in bridge decks*. Lawrence, KS: The University of Kansas Center for Research, Inc.

Kansas Department of Transportation (KDOT). (2007). Aggregates for on grade concrete (Special Provision 07-11004-R07). *Special provision to the standard specifications, 2007 Edition*. Topeka, KS: Author.

Appendix

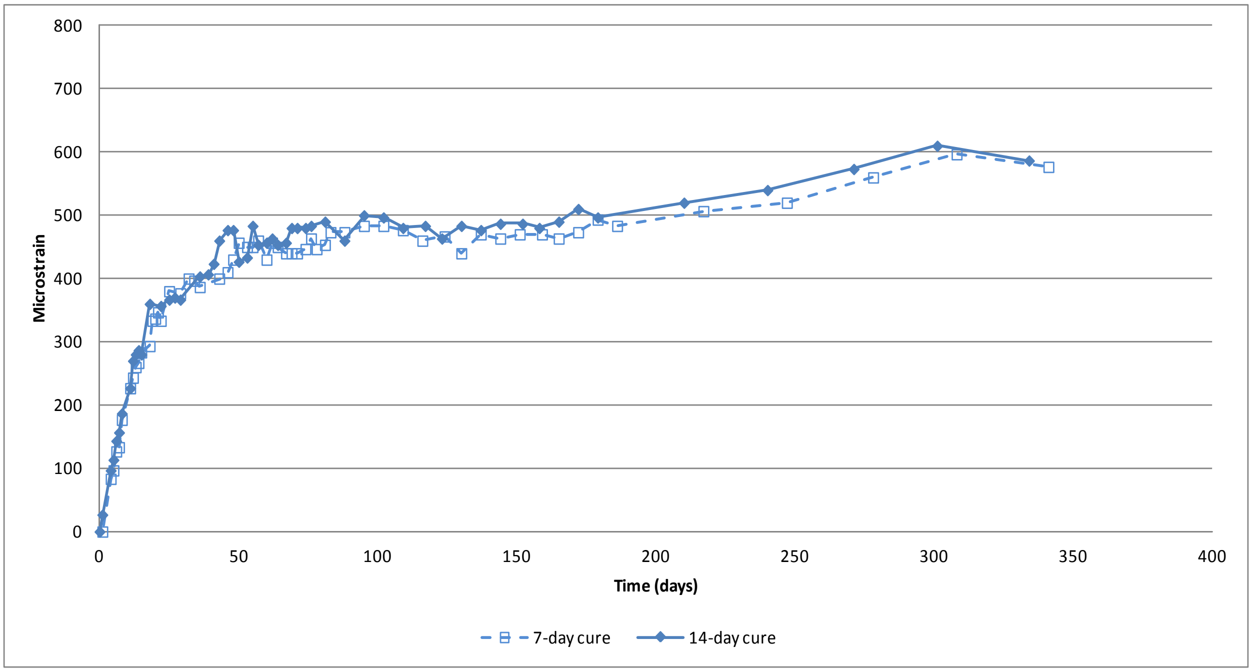

Figure A.1: Batch 1; 10-0092; TMA-1 w/0% Volc. Ash

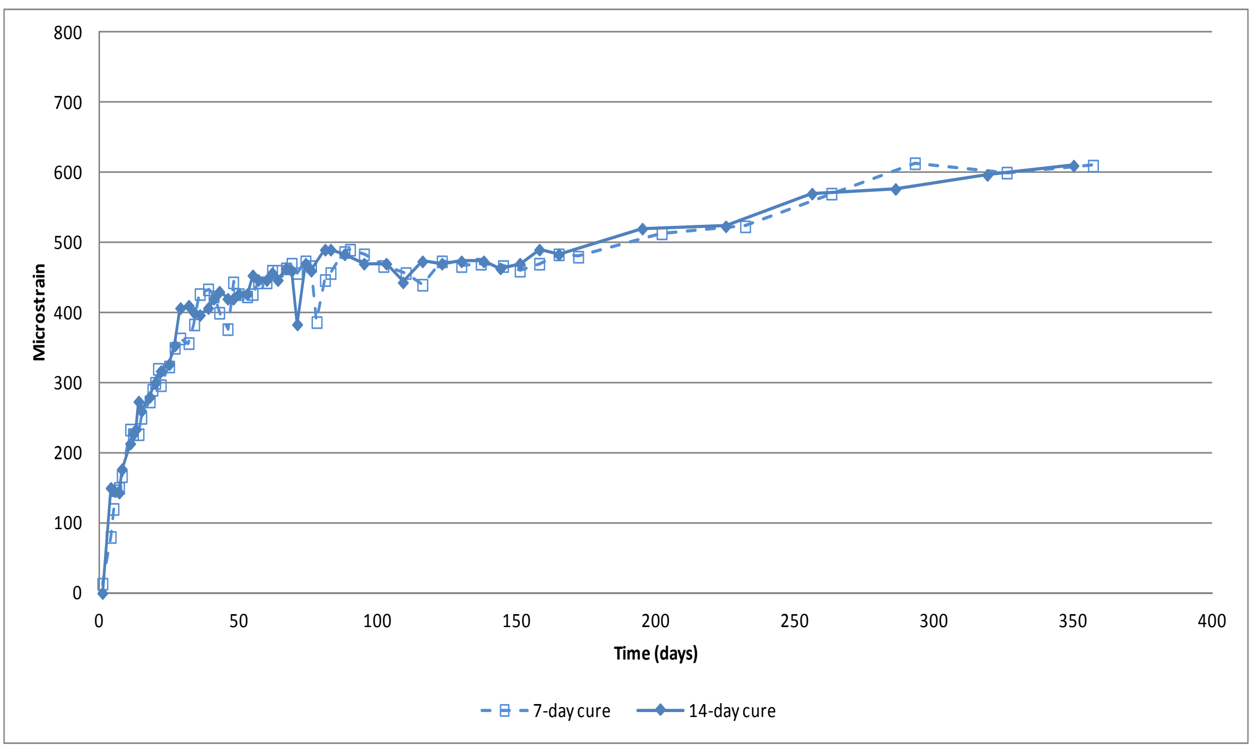

Figure A.2: Batch 5; 10-0177; TMA-1 w/20% Volc. Ash

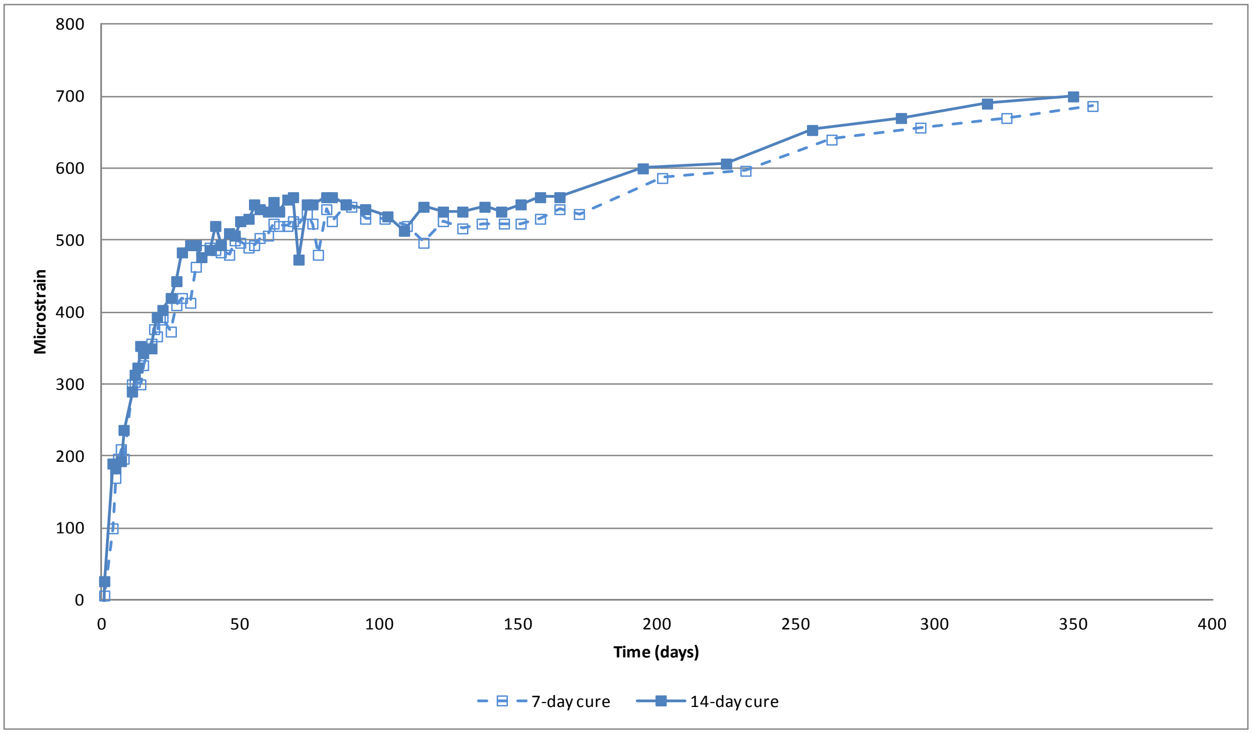

Figure A.3: Batch 6; 10-0178; TMA-1 w/40% Volc. Ash

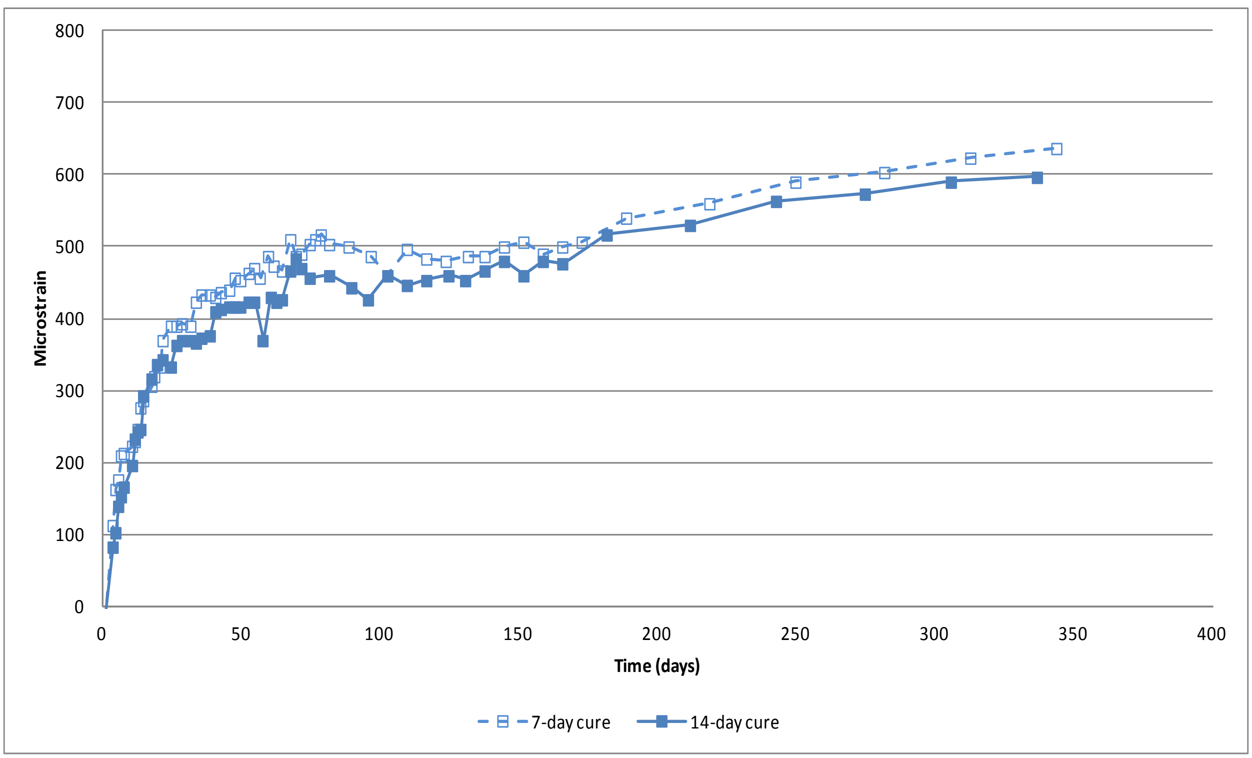

Figure A.4: Batch 7; 10-0253; TMA-2 w/20% Volc. Ash

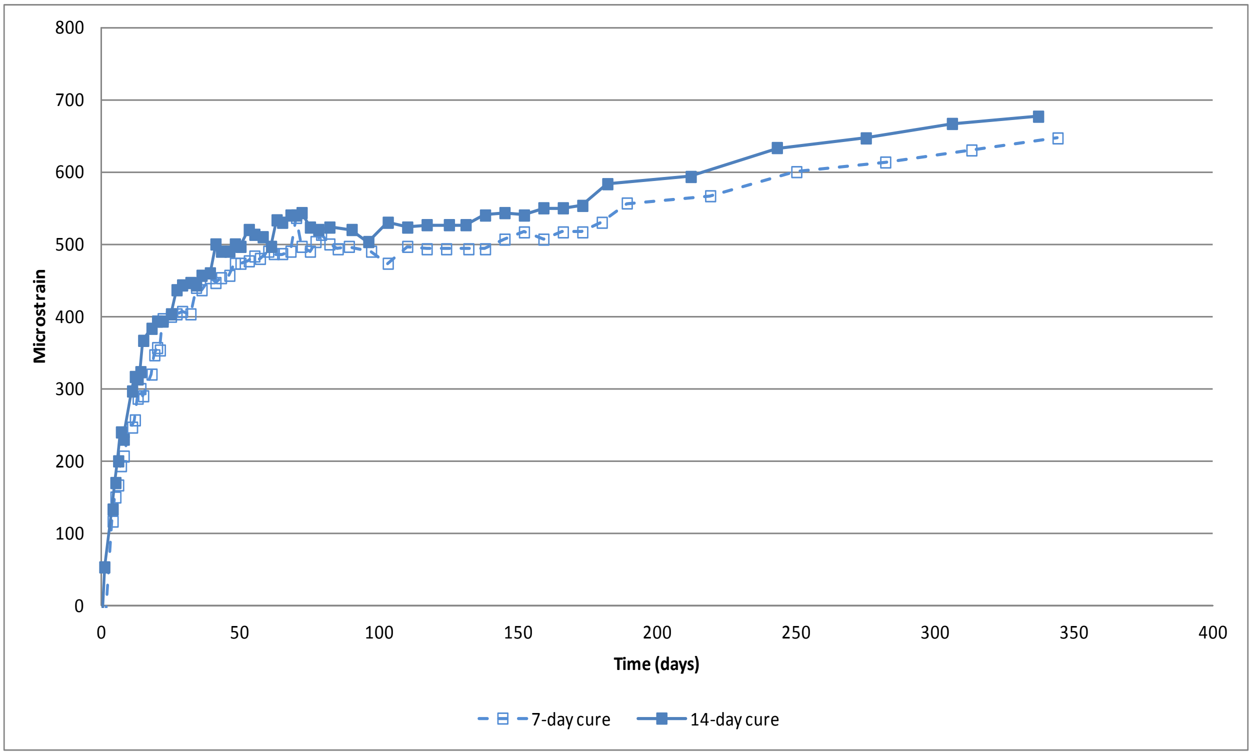

Figure A.5: Batch 8; 10-0254; TMA-2 w/40% Volc. Ash

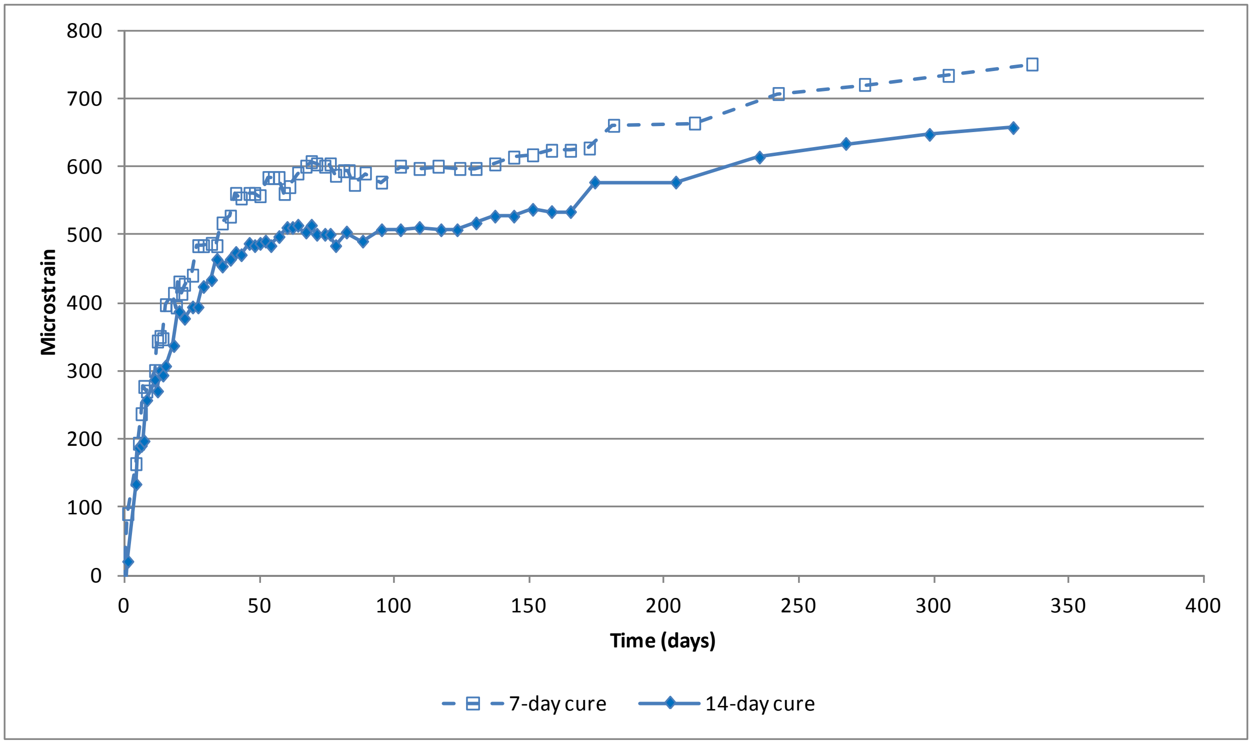

Figure A.6: Batch 9; 10-0344; TMA-1 w/0% Volc. Ash

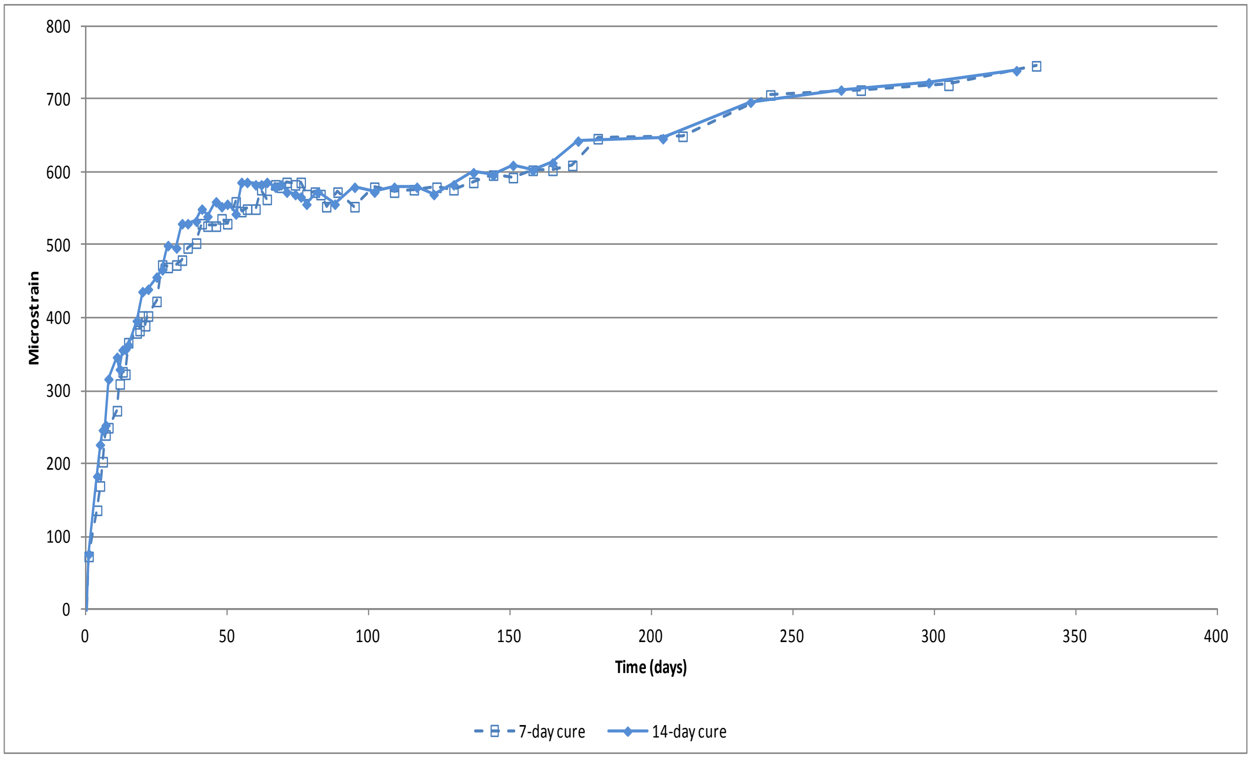

Figure A.7: Batch 10; 10-0345; TMA-2 w/20% Volc. Ash

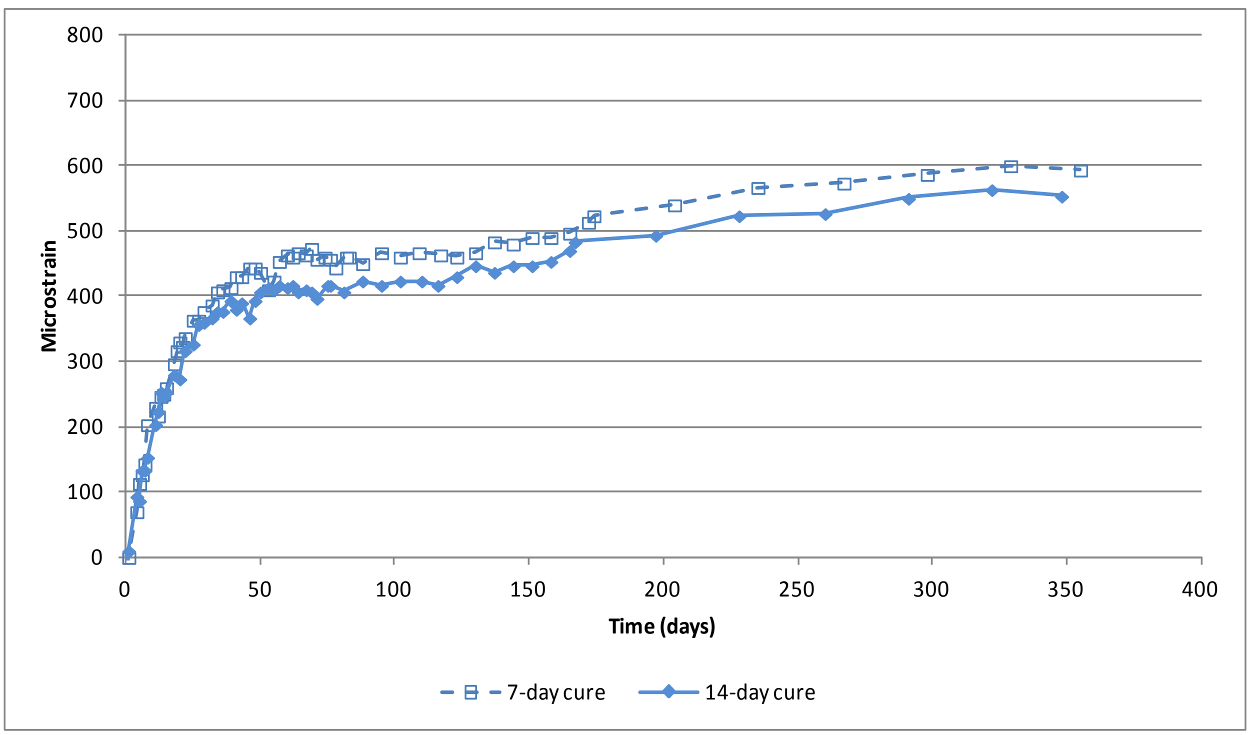

Figure A.8: Batch 11; 10-0390; LS-2 w/20% Volc. Ash

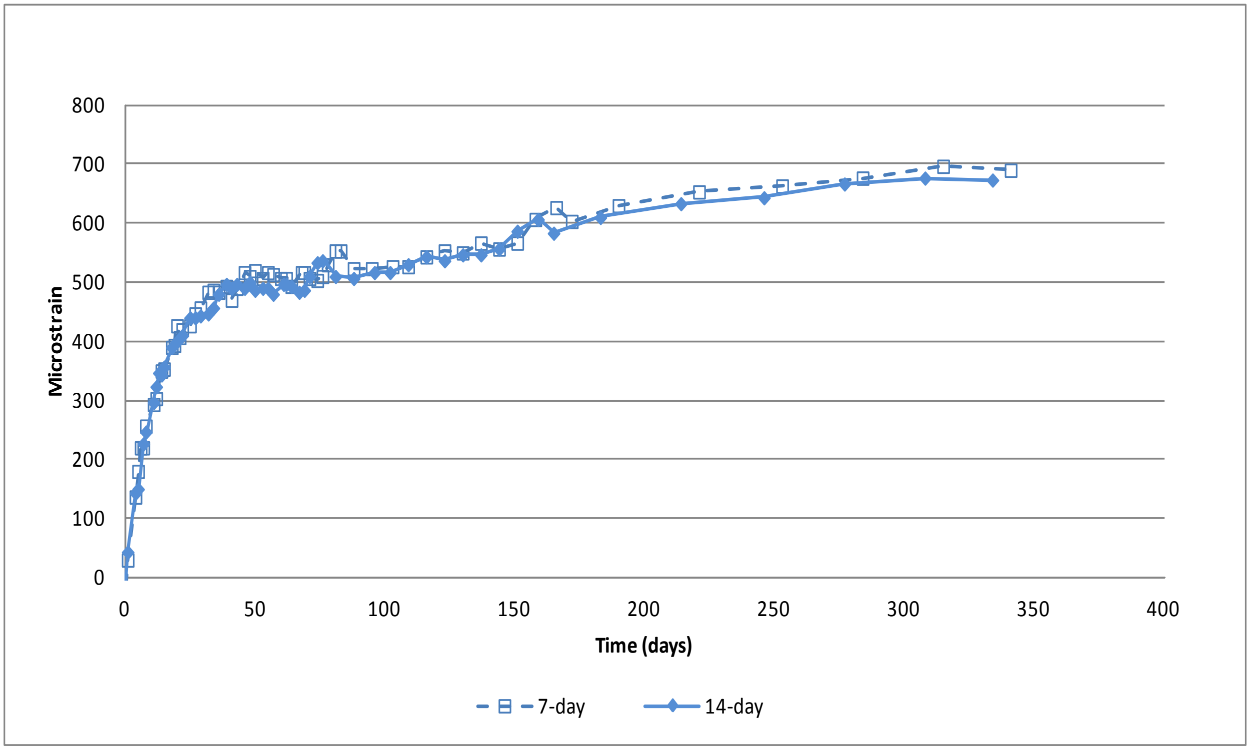

Figure A.9: Batch 12; 10-0483; LS-2 w/40% Volc. Ash

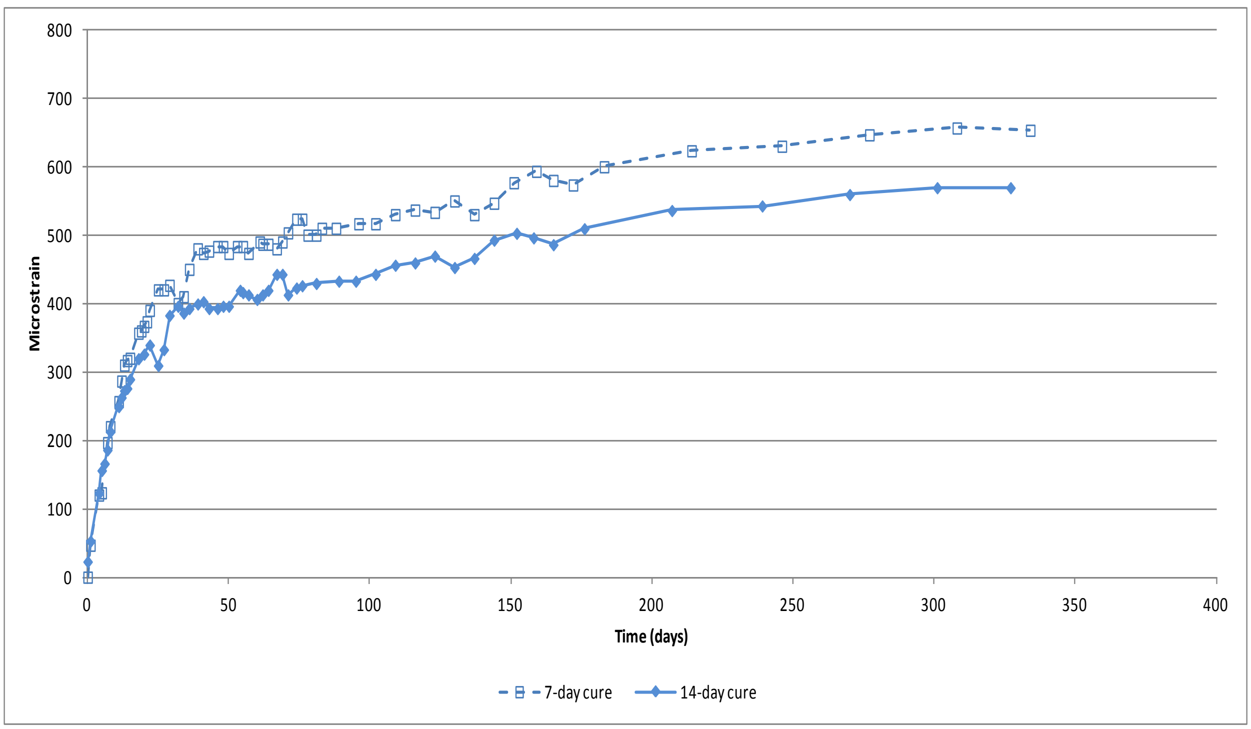

Figure A.10: Batch 13; 10-0542; LS-2 w/0% Volc. Ash

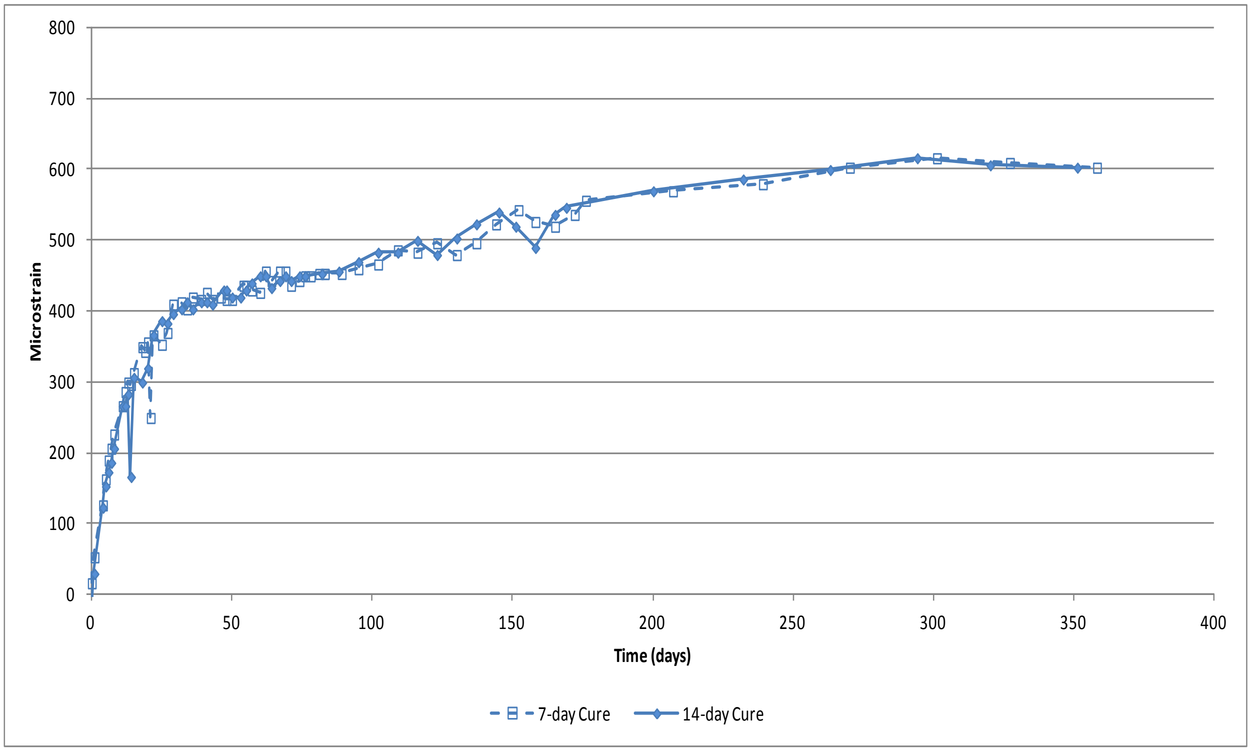

Figure A.11: Batch 14; 10-0639; LS-2 w/40% Volc. Ash

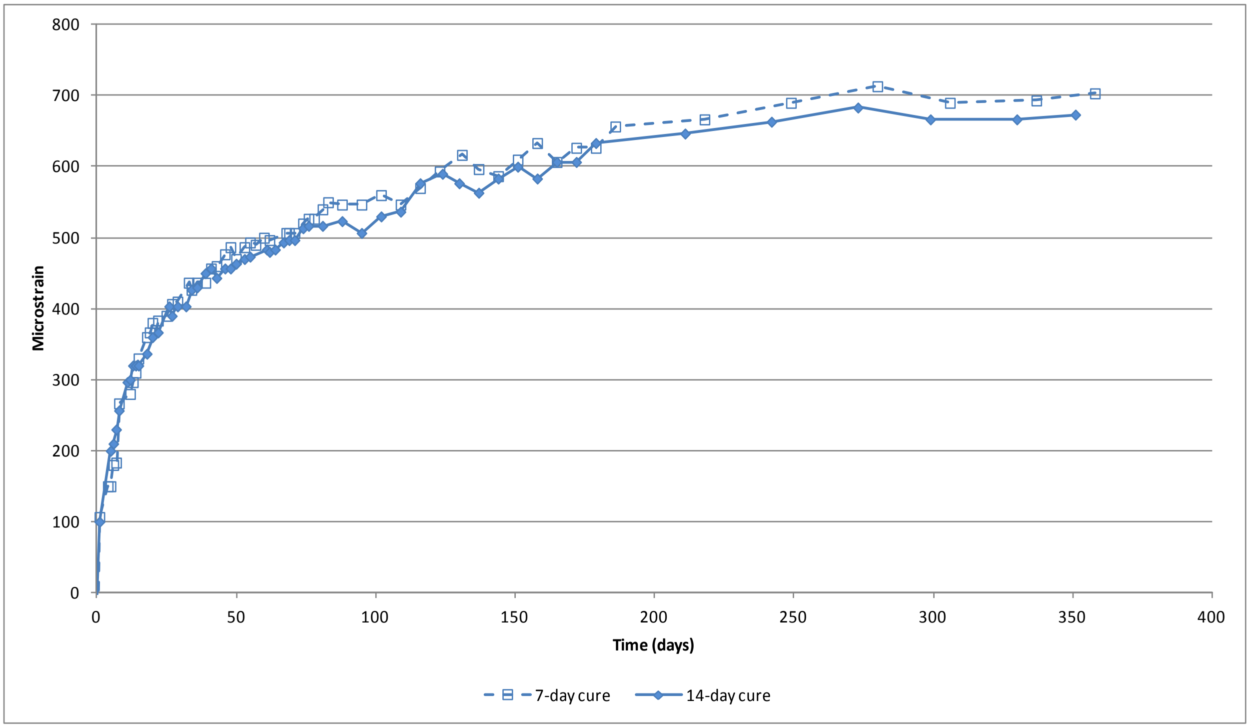

Figure A.12: Batch 15; 10-0956; LS-2 w/10% Volc. Ash

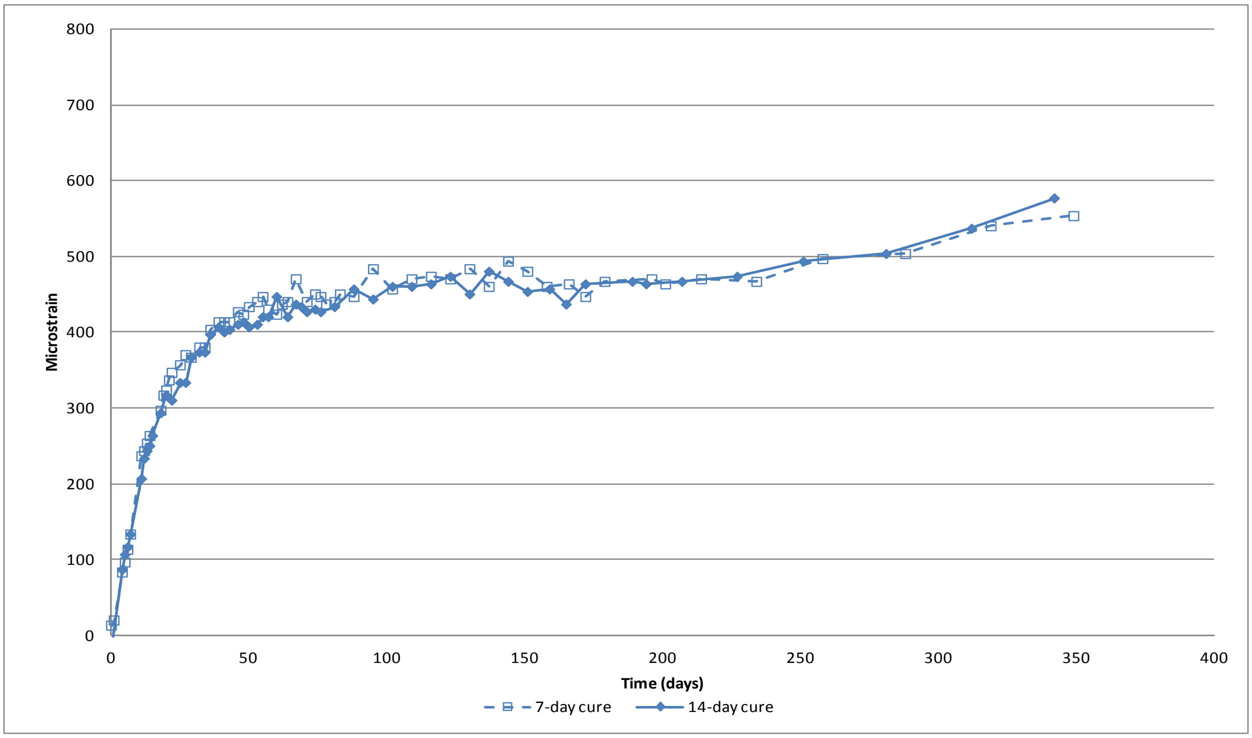

Figure A.13: 09-3513; LS-1 100% Cement

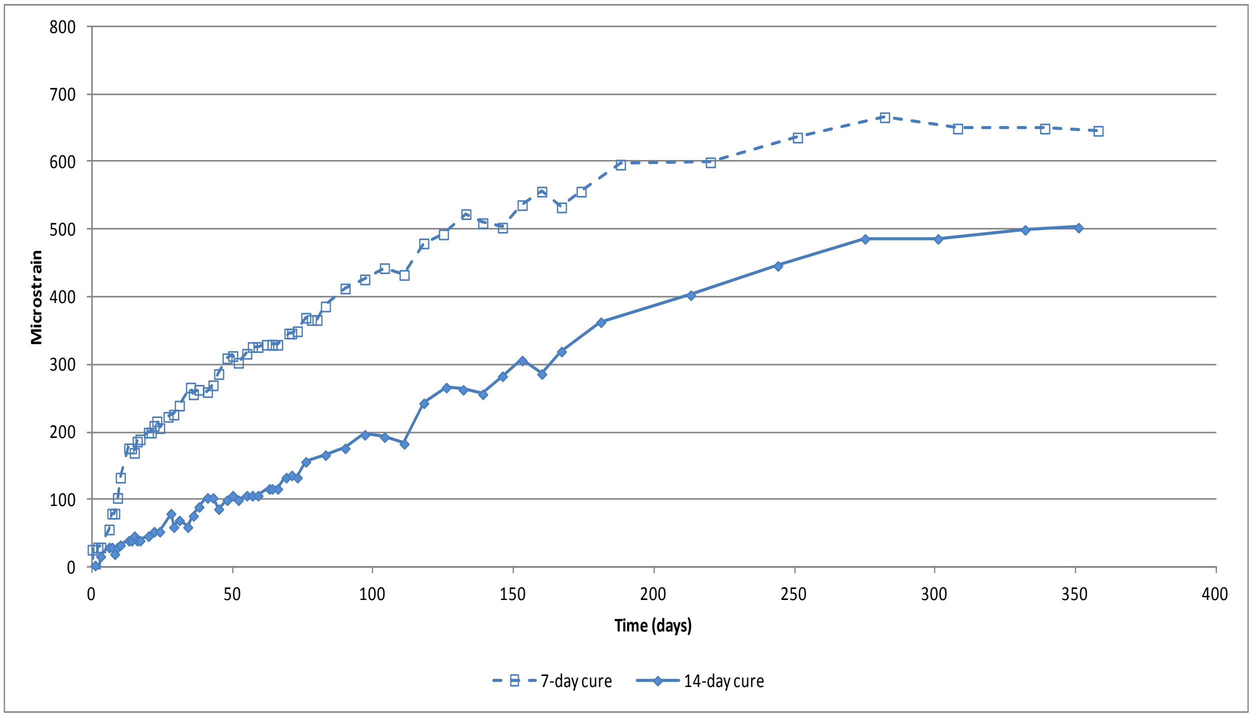

Figure A.14: 10-0915; C0536 Bridge 075; LW Agg.

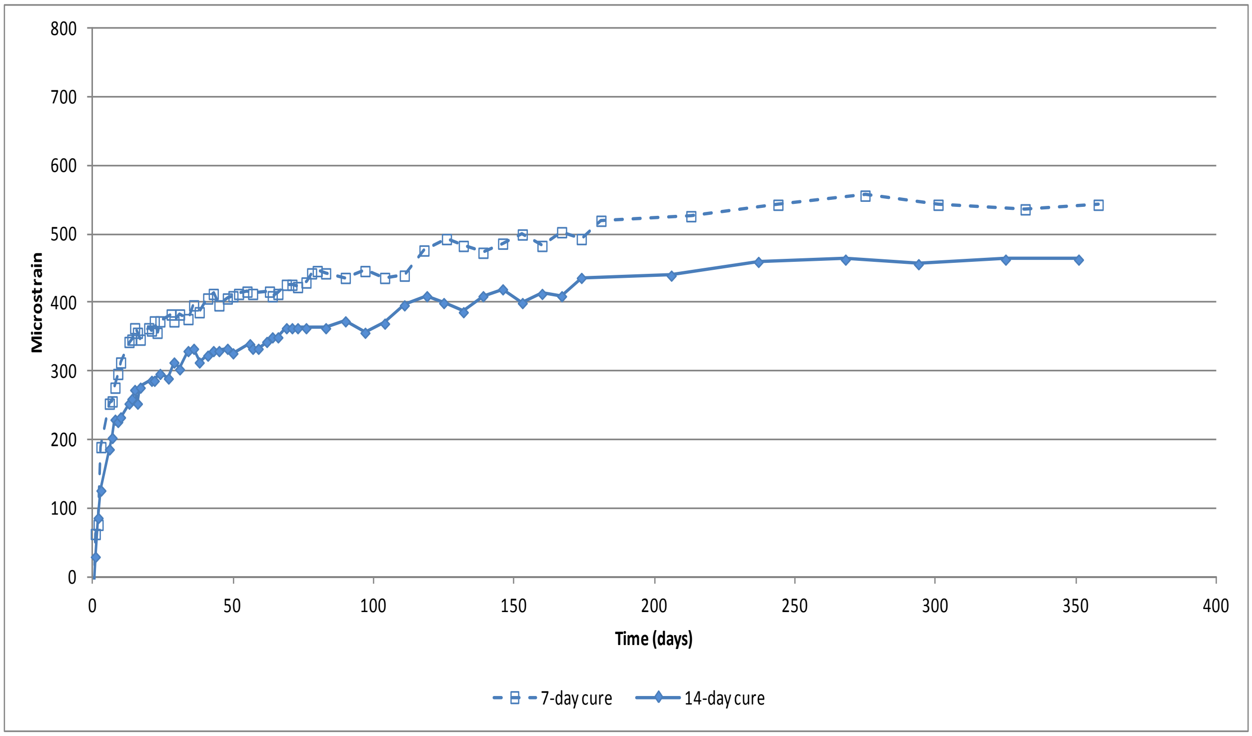

Figure A.15: 10-1012; K-10 Bridge 180; Granite-4% SF/19% F-Ash

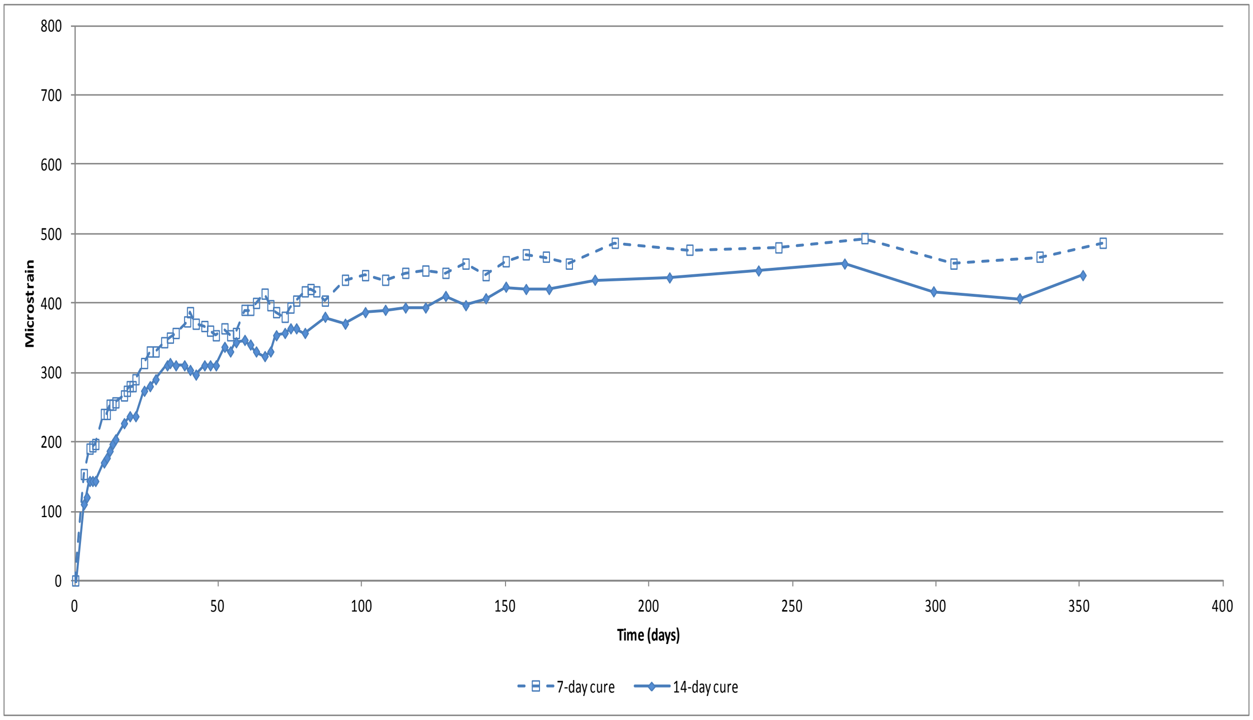

Figure A.16: 10-2203; US-59 Bridge 112; Granite-5% SF/35% GGBFS

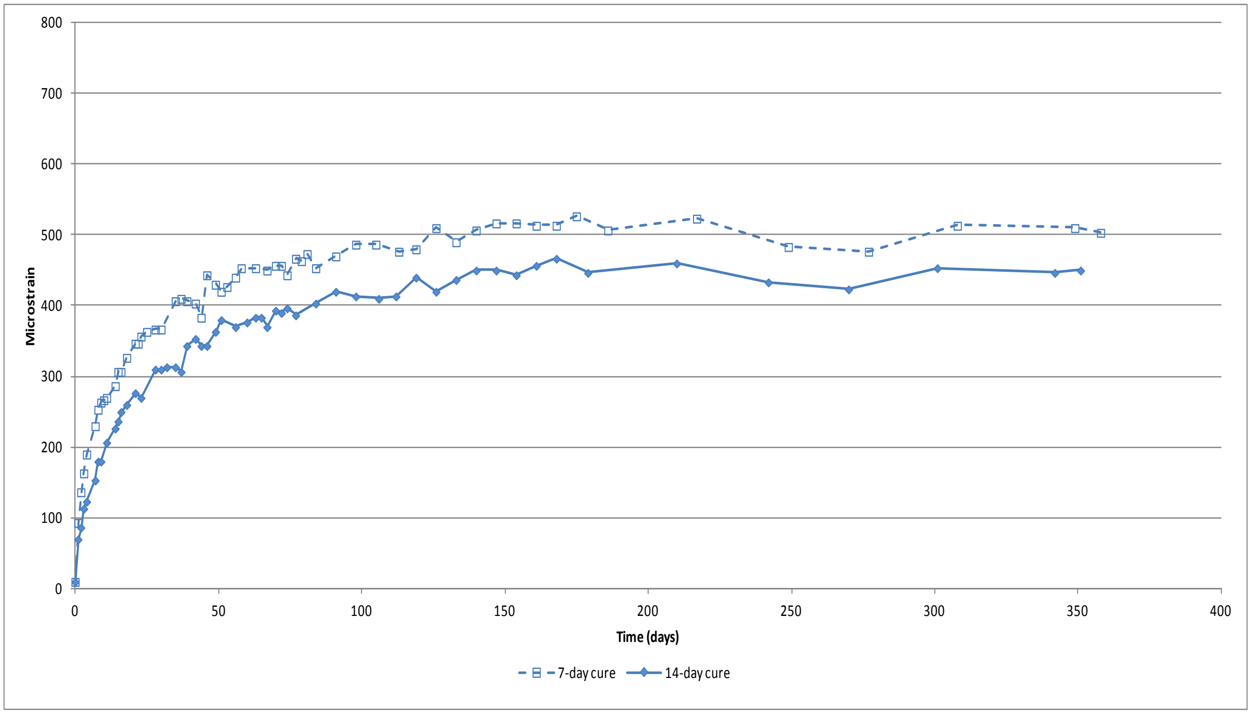

Figure A.17: 10-2995; US-59 Bridge 114; Granite-5% SF/35% GGBFS

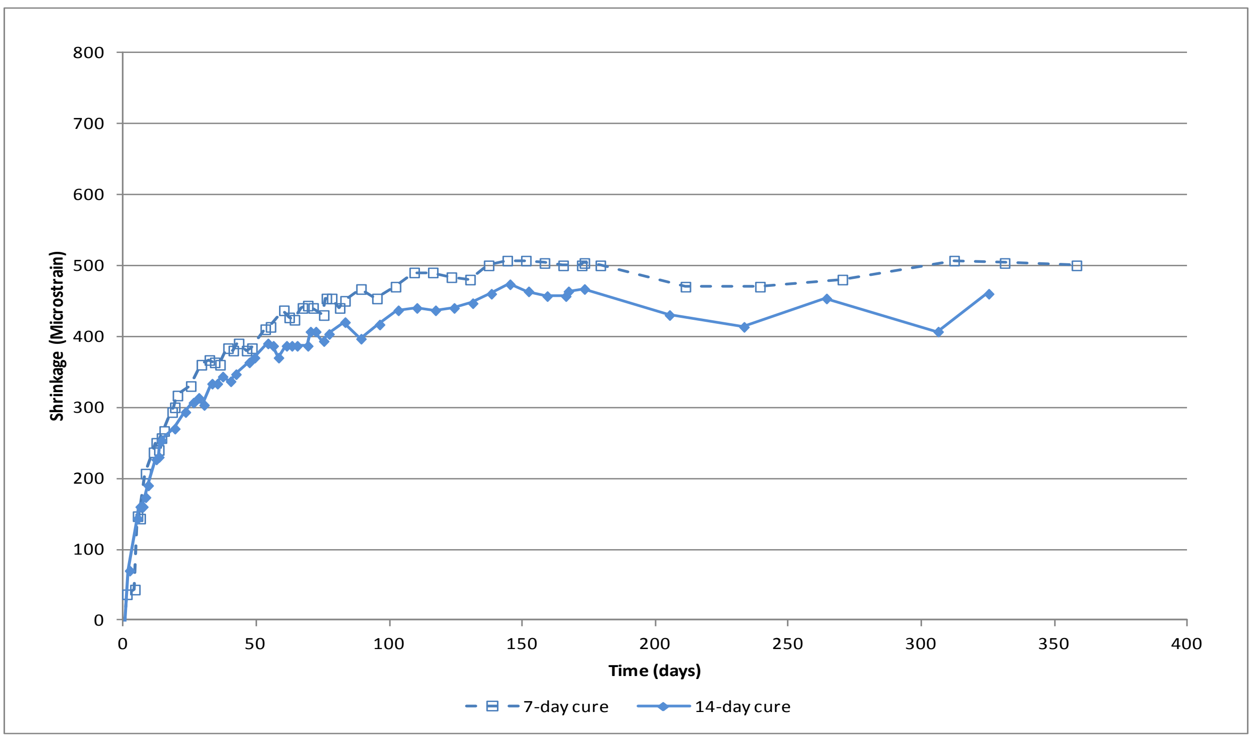

Figure A.18: 10-3463; K-7 Bridge 352; Granite 100% Cement

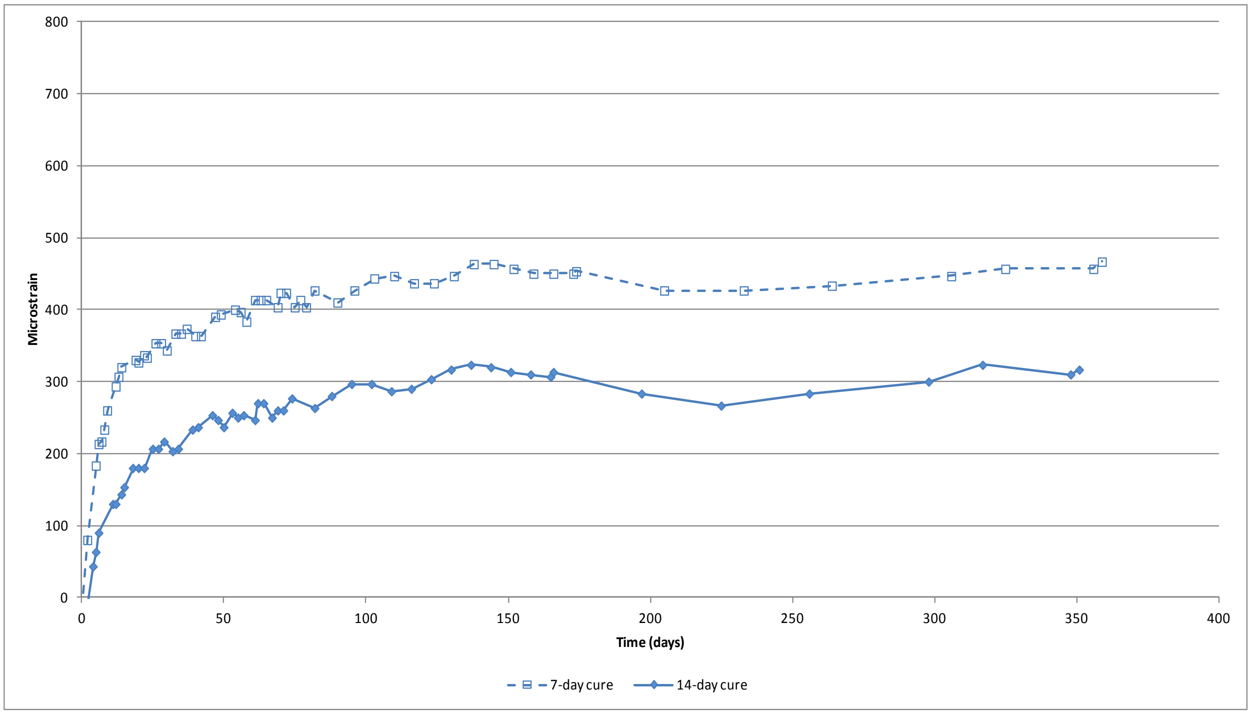

Figure A.19: 10-3529; US-59 Bridge 115; Granite-5% SF/35% GGBFS

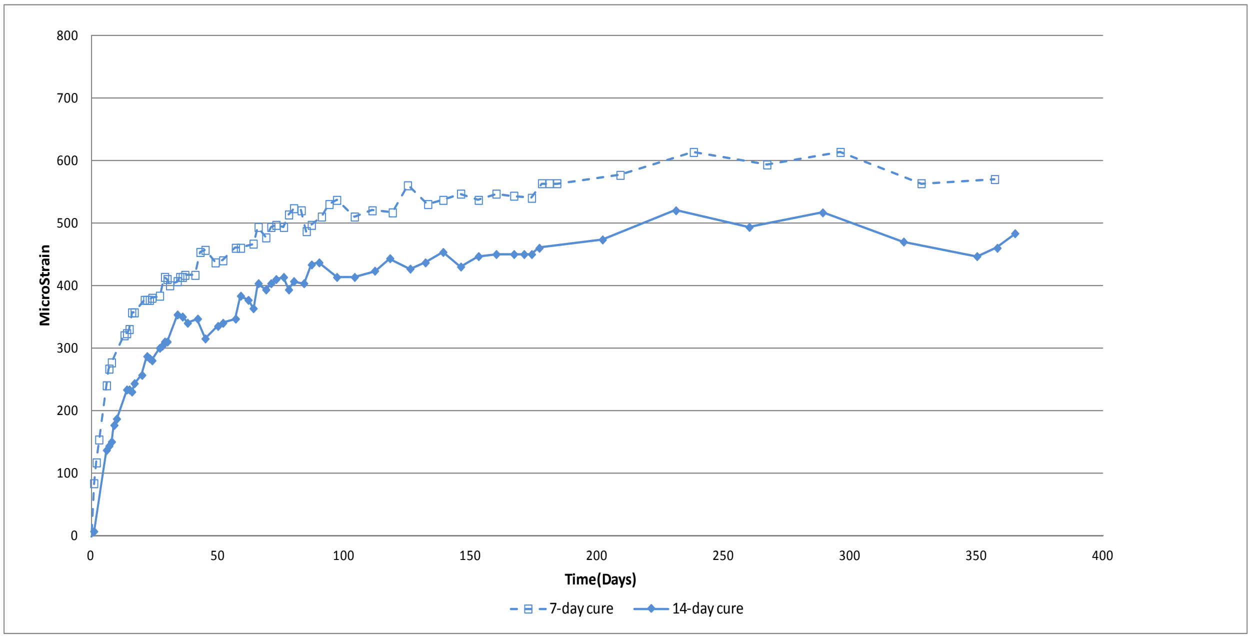

Figure A.20: 11-0849; K-18 Bridge 066; Granite-5% SF/35% GGBFS