Louisiana Transportation Research Center

Final Report 573

Laboratory Evaluation of 100 Percent Fly Ash Cementitious Systems

by

Tyson Rupnow, Ph.D., P.E.
Patrick Icenogle, P.E.
Zachary Collier, E.I.
Amar Raghavendra, P.E.

LTRC

4101 Gourrier Avenue | Baton Rouge, Louisiana 70808
(225) 767-9131 | (225) 767-9108 fax | www.ltrc.lsu.edu

TECHNICAL REPORT STANDARD PAGE

1. Report No. **FHWA/LA.15/573**	2. Government Accession No.	3. Recipient's Catalog No.
4. Title and Subtitle **Laboratory Evaluation of 100 Percent Fly Ash Cementitious Systems**	5. Report Date December 2016 6. Performing Organization Code LTRC Project Number: 13-2C State Project Number: 30001502	
7. Author(s) Tyson D. Rupnow, Patrick Icenogle, Zachary Collier, Amar Raghavendra	8. Performing Organization Report No.	
9. Performing Organization Name and Address Louisiana Transportation Research Center 4101 Gourrier Avenue Baton Rouge, LA 70808	10. Work Unit No. 11. Contract or Grant No.	
12. Sponsoring Agency Name and Address Louisiana Department of Transportation and Development P.O. Box 94245 Baton Rouge, LA 70804-9245	13. Type of Report and Period Covered **Final Report** **07/13 – 06/15** 14. Sponsoring Agency Code	

15. Supplementary Notes

Conducted in Cooperation with the U.S. Department of Transportation, Federal Highway Administration

16. Abstract

Long-lasting, durable concrete is a must have for Departments of Transportation (DOT's) in today's construction and economic climate. Many entities are turning to alternative concrete mixtures to ensure long-term durability such as ternary mixtures, lower w/cm ratios, lower cementitous materials contents, and alternative binders such as Ekkomaxx. The use of fly ash as a sole binder production of portland cement concrete can be difficult and the aforementioned product allows the control of the set times to allow better usage of class C fly ash as the sole binder.

Thirty-six mixtures were prepared and duplicated in the laboratory to determine the effects of activator dosage, fly ash content, and water content. The fresh properties of slump, air content, and set time were measured. Hardened properties tested included compressive and flexural strength, length change, and surface resistivity.

The slump results show that the w/a ratio affect the slump greater than the admixture dosage rate. Generally, the slump increases as dosage rate increases, but the trend would be considered fair as the w/a changes between the different admixture dosage rates.

The time between initial and final set was very short. This is of concern to the authors due to the fact that this is the period in which the concrete material has to be finished and textured. In a controlled laboratory environment, this can be completed rather easily. In an ambient environment, many effects come into play such as wind speed, temperature, and relative humidity. The short window may be a barrier to full-scale implementation. Overdosing the admixture has a negative effect of producing concrete that does not set within a 24-hour time period, and sometimes not even within 36 hours.

The hardened concrete properties show that many of the mixtures will meet or exceed Louisiana Department of Transportation and Development (DOTD) requirements for compressive strength and surface resistivity. The results show that the overall strength is dependent upon admixture dosage rate, followed by the w/a ratio and ash content, respectively. Although these mixtures will meet or exceed requirements, care should be exercised when utilizing this material; a trial batch is recommended for all applications.

The authors recommend that a discussion between the materials administrator, AML representatives for concrete materials, and the PRC be held to discuss future usage of this product. Key points in the discussion will be to designate the product under the chemical admixture or cement designation(s)

17. Key Words class c fly ash, geopolymer, ekkomaxx		18. Distribution Statement **Unrestricted. This document is available through the National Technical Information Service, Springfield, VA 21161.**	
19. Security Classif. (of this report)	20. Security Classif. (of this page)	21. No. of Pages 50	22. Price

Project Review Committee

Each research project will have an advisory committee appointed by the LTRC Director. The Project Review Committee is responsible for assisting the LTRC Administrator or Manager in the development of acceptable research problem statements, requests for proposals, review of research proposals, oversight of approved research projects, and implementation of findings.

LTRC appreciates the dedication of the following Project Review Committee Members in guiding this research study to fruition.

LTRC Administrator

Samuel Cooper, III, Ph.D., P.E.
Materials Research Administrator

Members

Chris Abadie
Hector Santiago
John Eggers
George Thompson
Luanna Cambas

Directorate Implementation Sponsor

Janice P. Williams, P.E.
DOTD Chief Engineer

Laboratory Evaluation of 100 Percent Fly Ash Cementitious Systems

by

Tyson Rupnow, Ph.D., P.E.
Patrick Icenogle, P.E.
Zachary Collier, E.I.
Amar Raghavendra, P.E.

Louisiana Transportation Research Center
4101 Gourrier Avenue
Baton Rouge, LA 70808

LTRC Project No. 13-2C
State Project No. 30001502

conducted for

Louisiana Department of Transportation and Development
Louisiana Transportation Research Center

December 2016

ABSTRACT

Long-lasting, durable concrete is a must have for Departments of Transportation (DOTs) in today's construction and economic climate. Many entities are turning to alternative concrete mixtures to ensure long-term durability such as ternary mixtures, lower w/cm ratios, lower cementitous materials contents, and alternative binders such as Ekkomaxx. The use of fly ash as a sole binder production of portland cement concrete can be difficult and the aforementioned product allows the control of the set times to allow better usage of class C fly ash as the sole binder.

Thirty-six mixtures were prepared and duplicated in the laboratory to determine the effects of activator dosage, fly ash content, and water content. The fresh properties of slump, air content, and set time were measured. Hardened properties tested included compressive and flexural strength, length change, and surface resistivity.

The slump results show that the w/a ratio affect the slump greater than the admixture dosage rate. Generally, the slump increases as dosage rate increases, but the trend would be considered fair as the w/a changes between the different admixture dosage rates.

The time between initial and final set was very short. This is of concern to the authors due to the fact that this is the period in which the concrete material has to be finished and textured. In a controlled laboratory environment, this can be completed rather easily. In an ambient environment, many effects come into play such as wind speed, temperature, and relative humidity. The short window may be a barrier to full-scale implementation. Overdosing the admixture has a negative effect of producing concrete that does not set within a 24-hour time period, and sometimes not even within 36 hours.

The hardened concrete properties show that many of the mixtures will meet or exceed Louisiana Department of Transportation and Development (DOTD) requirements for compressive strength and surface resistivity. The results show that the overall strength is dependent upon admixture dosage rate, followed by the w/a ratio and ash content, respectively. Although these mixtures will meet or exceed requirements, care should be exercised when utilizing this material; a trial batch is recommended for all applications.

The authors recommend that a discussion between the materials administrator, AML representatives for concrete materials, and the PRC be held to discuss future usage of this product. Key points in the discussion will be to designate the product under the chemical admixture or cement designation(s).

ACKNOWLEDGMENTS

The U.S. Department of Transportation, Federal Highway Administration (FHWA), Louisiana Department of Transportation and Development (DOTD), and Louisiana Transportation Research Center (LTRC) financially supported this research project.
The efforts of Greg Tullier, Norris Rosser, and Craig Johnson in the concrete laboratory are greatly appreciated. The efforts of George Thompson and Ceratech are also greatly appreciated.

IMPLEMENTATION STATEMENT

The authors recommend that a discussion between the materials administrator, AML representatives for concrete materials, and the PRC be held to discuss future usage of this product. General discussion will be to include it as a cementitous system or whether to include it as a chemical admixture. Regardless of inclusion, trial batches should be performed when utilizing this material to determine setting time characteristics.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

INTRODUCTION

Long-lasting, durable concrete is a must have for DOTs in today's construction and economic climate. Many entities are turning to alternative concrete mixtures to ensure long-term durability such as ternary mixtures, lower w/cm ratios, lower cementitous materials contents, and alternative binders such as Ekkomaxx. This project evaluated concrete produced with 100 percent fly ash combined with an activator provided by Ceratech. The use of fly ash as a sole binder production of portland cement concrete can be difficult and the aforementioned product allows the control of the set times to allow better usage of class C fly ash as the sole binder. This project will enable the owner (Ceratech) and the user (DOTD) to gain a more in-depth understanding of the interactions associated with the use of 100 percent class C fly ash systems produced with Ceratech's activator.

Literature Review

This section details past research work with fly ash cementitous based systems. Geopolymers are discussed as well as properties of class C fly ash.

Geopolymer cement is comprised of an aluminosilicate material such as fly ash or metakaolin combined with an alkaline reagent and water. The material properties such as set time and strength gain can be temperature dependent. According to a publication by FHWA in 2010 geopolymer concrete material is still in its infancy and a number of advancements are needed [*1*]. Geopolymer concrete does have advantages including reduced carbon footprint and energy savings when compared to traditional portland cement concrete. Current research efforts worldwide are focusing on production of geopolymer cements that that are able to be mixed with low alkali solutions and cure in a reasonable time under ambient conditions [*2*].

ASTM C618 [Standard Specification for Coal Fly Ash and Raw or Calcined Natural Pozzolan for Use in Concrete] defines fly ash as the fine residue produced from the burning of ground or powdered coal [*3*]. Fly ash is collected from the flue gas of coal-fired boilers by the means of an electrostatic precipitator or bag house. Fly ash color may vary from tan to gray [*4*]. Self-cementing fly ash is produced from the burning of low sulfur, subbituminous, and lignite coals. Fly ash particles are typically spherical in nature and contain some crystalline as well as carbonaceous matter [*4, 5*]. Misra noted that a large percentage of fly ash is in the form of silica, alumina, ferric oxide, and calcium oxide [*4*]. Table 1 shows typical class C fly ash composition. ASTM C618 chemical requirements are also shown in Table 1.

ASTM C618 states, "A pozzolan is a material rich in silica and alumina that has little or no self-cementing properties, but will, in the presence of moisture, chemically react with calcium hydroxide at ordinary temperatures to form compounds possessing cementitious properties [*3*]."

Research states that the pozzolinity of fly ash is mainly dependent upon the fineness of the ash, amounts of silica and alumina, and the presence of moisture and free lime [*4, 5*]. Winkerton and Pamukcu also state that density, amount of carbon, temperature, and age also affect the rate of pozzolanic reaction [*6*].

Table 1
Typical chemical composition of a class C fly ash and ASTM C 618 chemical requirements for a class C fly ash

Oxide	Self Cementing Fly Ash (% of Total Weight)	ASTM C 618	DOTD (AASHTO M295)
SiO_2	20-40	Summation between 50% and 70%	Summation between 50% and 70%
Al_2O_3	10-30		
Fe_2O_3	3-10		
CaO	10-32		
MgO	0.8-8		
Na_2O	0.5-6		
K_2O	0.5-4		
TiO_2	0.5-2		
SO_3	1-8	Maximum of 5%	Maximum of 5%
LOI	0-3	Maximum of 5%	Maximum of 5%

OBJECTIVE

The objectives of this research were to characterize the concrete produced with Ekkomaxx and determine all effects with respect to the activator dosage rate, water to ash ratio, and ash content.

SCOPE

To meet the objectives of this project, a full factorial was developed with activator dosages ranging from 0.2 to 0.5 gallon per hundred weight (cwt), fly ash binder contents ranging from 600 to 800 pounds per cubic yard (pcy), and water to ash (w/a) ratio ranging from 0.2 to 0.4. The activator dosages were varied in increments of 0.1 gallon/cwt, the fly ash contents were varied in increments of 100 lb., and the w/a was varied in increments of 0.1. In order to determine effects and repeatability, each mixture was duplicated.

Fresh concrete properties measured included air content, unit weight, and set time. Hardened concrete properties of compressive and flexural strength, free shrinkage, and surface resistivity were measured for each mixture. Samples were produced and cured in 100 percent relative humidity conditions. Compressive and flexural strength were measured at 7-, 28-, and 56-days of age. Surface resistivity was measured at 28-, 56-, and 90-days of age.

METHODOLOGY

This section is divided into the materials and test methods used for the project. In order to determine main effects and interactions between the water content, admixture dosage rate, and fly ash content, a full factorial was used (Mix #1) and each mixture was duplicated (Mix #2).

Materials

The class C fly ash used in this study originated from the Big Cajun power plant located in New Roads, LA. The chemical characterization results for the class C fly ash are shown in Table 2. Mixtures incorporated No. 67 limestone and a natural sand as the coarse and fine aggregate, respectively. The coarse to fine aggregate ratio was kept near 60:40. The cementitous contents, water to ash ratios (w/a), and activator dosage rates are shown in Table 3.

The target w/a ratio were chosen to get a wide range of material properties, but it was determined after several iterations in the laboratory that the mixtures at the low and high w/a ratio were extremely dry or extremely wet, respectively. The team then decided to fine tune to w/a (see actual w/a in Table 3) to obtain more workable concrete at the lower and higher water contents.

The admixture used in this study is termed "activator" by Ceratech and is noted as BA200. This proprietary admixture is most likely a combination of an acid-based material combined with a retarder. This acid activates the ash toward setting and strength gain while the retarder controls the tendency of the class C fly ash to flash set.

After obtaining the fly ash for the study, trial batches were performed using the 0.2 gal/cwt admixture dosage rate, and the research team noted that the material did not set. Ceratech was consulted and the chemical characterization results were studied. It was noted that the chemical composition of the ash was slightly different from what had been previously tested in the laboratory. The team then decided to incorporate two Ceratech admixtures, BA100 and BA200 to obtain a workable, setting mixture. The final dosage was divided into a 20 percent modifier (BA100) and 80 percent activator (BA200). Note the BA100 modifier is essentially the activator, minus the retarder. The water content in the admixtures was accounted for and the mixing water was adjusted accordingly in the batching process.

Table 2
Chemical characterization results for the class C fly ash used in this study

Oxide	Class C Fly Ash
SiO_2	34.81
Al_2O_3	17.47
Fe_2O_3	6.51
CaO	26.22
MgO	6.59
Na_2O	1.89
K_2O	0.41
TiO_2	1.33
SO_3	1.63
LOI	0.60

Table 3
Laboratory test matrix noting the activator dosage, fly ash content, target w/a, and actual w/a, and LTRC laboratory number

Activator Dosage (gal/cwt)	Fly Ash Content (pcy)	Target w/a	Actual w/a	LTRC Lab Number (Mix 1)	LTRC Lab Number (Mix 2)
0.2	600	0.2	0.20	C-4072	C-4073
		0.3	0.30	C-4074	C-4075
		0.4	0.40	C-4076	C-4077
	700	0.2	0.20	C-4079	C-4080
		0.3	0.30	C-4081	C-4082
		0.4	0.40	C-4083	C-4084
	800	0.2	0.25	C-4089	C-4090
		0.3	0.30	C-4091	C-4092
		0.4	0.35	C-4095	C-4096
0.3	600	0.2	0.25	C-4135	C-4136
		0.3	0.30	C-4137	C-4138
		0.4	0.35	C-4159	C-4160
	700	0.2	0.25	C-4161	C-4162
		0.3	0.30	C-4163	C-4164
		0.4	0.35	C-4165	C-4166
	800	0.2	0.20	C-4169	C-4170
		0.3	0.25	C-4171	C-4172
		0.4	0.30	C-4173	C-4174
0.4	600	0.2	0.20	C-4175	C-4176
		0.3	0.25	C-4179	C-4180
		0.4	0.30	C-4181	C-4182
	700	0.2	0.20	C-4183	C-4184
		0.3	0.25	C-4185	C-4186
		0.4	0.30	C-4187	C-4188
	800	0.2	0.20	C-4189	C-4190
		0.3	0.25	C-4191	C-4192
		0.4	0.30	C-4193	C-4194
0.5	600	0.2	0.20	C-4195	C-4196
		0.3	0.25	C-4200	C-4201
		0.4	0.30	C-4202	C-4203
	700	0.2	0.20	C-4214	C-4215
		0.3	0.25	C-4218	C-4219
		0.4	0.30	C-4216	C-4217
	800	0.2	0.20	C-4220	C-4221
		0.3	0.25	C-4222	C-4223
		0.4	0.30	C-4224	C-4225

Test Methods

This section will detail the test methods used in characterizing the concrete properties. The section is divided into the fresh concrete properties and hardened concrete properties.

Fresh Concrete Property Test Methods

The following test methods were used in characterization of the fresh concrete properties.

- ASTM C138 [Standard Test Method for Density (Unit Weight), Yield, and Air Content (Gravimetric) of Concrete] [*7*]
- ASTM C231 [Standard Test Method for Air Content of Freshly Mixed Concrete by the Pressure Method] [*8*]
- ASTM C403 [Standard Test Method for Time of Setting of Concrete Mixtures by Penetration Resistance] [*9*]

Hardened Concrete Property Test Methods

The following test methods were used in characterization of the hardened concrete properties. Note that samples were tested in triplicate and stored in a 100 percent relative humidity environment until the age of testing.

- ASTM C39 [Standard Test Method for Compressive Strength of Cylindrical Concrete Specimens] [*10*]
- ASTM C78 [Standard Test Method for Flexural Strength of Concrete (Using Simple Beam with Third-Point Loading)] [*11*]
- ASTM C 157/157M [Standard Test Method for Length Change of Hardened Hydraulic-Cement Mortar and Concrete] [*12*]
    - Note the samples were stored in the 50 percent relative humidity room after initial curing until time of testing
- DOTD TR 233 [Test Method for Surface Resistivity Indication of Concrete's Ability to Resist Chloride Ion Penetration] [*13*]

DISCUSSION OF RESULTS

This section is divided into the fresh and hardened concrete property results.

Fresh Concrete Properties

This section will detail the fresh concrete properties. Table 4 to Table 7 show the fresh concrete properties of slump, air content, unit weight, and initial and final set time for each mixture. The results show that the mixtures, especially the 0.2 gal/cwt mixtures, the extreme ends were highly unworkable. This prompted the research team to tighten the w/a ratio for the remaining mixtures until the mixtures were workable. The set time results showed that the material has a short working time, especially at the low dosage rate and the working time increases as the dosage rate is increased until the dosage rate exceeds 0.4 gal/cwt where the set time is extended significantly until the time to initial set is longer than 24 hours. The results show, for a large number of mixtures, that there is no significant difference between Mix #1 and Mix #2. The results that have no time to set indicate mixtures that took longer than 24 hours to set.

Table 4
Fresh concrete properties for mixtures containing 0.2 gal/cwt admixture

LTRC Lab #	Slump (in.)	Air (%)	Unit Weight (pcf)	Initial Set Time (hours)	Final Set Time (hours)
C-4072	0.00	11.9	139	0.40	1.01
C-4073	0.00	11.9	140	0.40	1.01
C-4074	1.75	2.0	152	0.42	0.75
C-4075	1.50	2.5	153	0.33	0.62
C-4076	9.50	1.0	150	1.03	2.40
C-4077	9.00	1.0	150	0.25	1.38
C-4079	0.00	13.3	131	1.37	3.15
C-4080	0.00	12.3	139	1.30	1.85
C-4081	5.25	1.3	152	0.43	0.77
C-4082	5.75	1.8	150	0.38	0.83
C-4083	10.00	0.7	151	0.93	1.62
C-4084	10.25	0.3	150	1.32	1.92
C-4089	4.25	1.9	153	0.75	0.93
C-4090	4.50	1.8	153	0.68	0.80
C-4091	8.50	0.8	153	1.07	1.42
C-4092	8.25	0.7	153	0.30	0.58
C-4095	10.00	1.4	149	0.83	1.25
C-4096	9.50	1.0	149	1.00	1.88

Table 5
Fresh concrete properties for mixtures containing 0.3 gal/cwt admixture

LTRC Lab #	Slump (in.)	Air (%)	Unit Weight (pcf)	Initial Set Time (hours)	Final Set Time (hours)
C-4135	1.25	2.4	154	1.42	1.62
C-4136	1.25	2.2	155	1.63	1.77
C-4137	7.50	1.2	154	1.62	1.88
C-4138	8.50	0.9	153	1.92	2.28
C-4159	8.25	1.0	153	2.08	2.30
C-4160	7.50	1.3	153	2.13	2.53
C-4161	2.50	2.0	154	1.72	2.05
C-4162	2.50	2.0	153	2.07	2.23
C-4163	7.00	1.8	154	1.95	2.22
C-4164	7.00	1.8	155	2.68	2.83
C-4165	10.00	0.8	151	3.67	4.18
C-4166	10.00	0.8	153	2.90	3.37
C-4169	4.00	1.8	154	1.78	1.88
C-4170	1.75	2.1	154	1.95	2.07
C-4171	7.00	1.4	153	2.32	2.40
C-4172	7.50	1.3	154	2.32	2.40
C-4173	9.00	0.5	152	0.87	1.08
C-4174	8.50	0.7	151	0.03	0.25

Table 6
Fresh concrete properties for mixtures containing 0.4 gal/cwt admixture

LTRC Lab #	Slump (in.)	Air (%)	Unit Weight (pcf)	Initial Set Time (hours)	Final Set Time (hours)
C-4175	0.00	6.0	145	3.88	4.08
C-4176	0.00	6.1	142	3.15	3.48
C-4179	1.75	2.2	153	—	—
C-4180	0.00	5.0	149	—	—
C-4181	1.75	2.4	153	—	—
C-4182	2.25	2.2	153	—	—
C-4183	2.00	2.5	154	4.73	4.88
C-4184	3.75	1.6	155	4.40	4.57
C-4185	3.00	1.9	154	4.53	4.73
C-4186	2.00	2.0	154	5.72	5.95
C-4187	7.00	1.2	154	6.28	6.58
C-4188	5.50	1.4	154	4.43	4.60
C-4189	0.00	3.3	151	3.92	4.27
C-4190	0.25	4.9	151	3.03	3.37
C-4191	6.00	1.4	154	5.38	5.50
C-4192	6.50	1.3	154	5.62	5.77
C-4193	10.00	0.5	152	—	—
C-4194	10.50	0.6	150	—	—

Table 7
Fresh concrete properties for mixtures containing 0.5 gal/cwt admixture

LTRC Lab #	Slump (in.)	Air (%)	Unit Weight (pcf)	Initial Set Time (hours)	Final Set Time (hours)
C-4195	0.00	5.2	140	—	—
C-4196	0.00	5.0	145	—	—
C-4200	1.50	1.5	157	8.15	8.43
C-4201	0.00	4.1	151	5.63	6.00
C-4202	6.75	1.5	155	—	—
C-4203	4.00	1.4	155	—	—
C-4214	0.00	3.4	150	3.85	15.35
C-4215	0.50	2.3	156	4.78	5.13
C-4216	9.50	0.6	149	—	—
C-4217	9.50	0.5	153	—	—
C-4218	5.25	1.4	154	—	—
C-4219	4.50	2.0	154	—	—
C-4220	3.50	1.8	154	—	—
C-4221	3.00	1.8	154	—	—
C-4222	9.25	1.1	153	—	—
C-4223	9.25	1.0	154	—	—
C-4224	10.00	0.3	152	—	—
C-4225	10.5	0.4	152	—	—

The slump results show that the w/a affects the slump greater than the admixture dosage rate. Generally the slump increases as dosage rate increases, but the trend considered fair as the w/a changes between the different admixture dosage rates. The lower w/a ratios results show that the mixtures' workability is highly dependent upon the w/a.

When looking at the times to initial and final set, it was observed that the time between initial and final set was very short. This is of concern to the authors due to the fact that this is the period in which the concrete material has to be finished and textured. In a controlled laboratory environment, this can be completed rather easily. In an ambient environment, many effects come into play such as wind speed, temperature, and relative humidity. The short window may be a barrier to full-scale implementation. Overdosing the admixture has a negative effect of producing concrete that does not set within a 24-hour time period, and sometimes not even within 36 hours. For these mixtures, the material was left in the forms until the technicians felt the concrete had set enough to strip the forms and place the samples in the 100 percent relative humidity room. The authors do believe that Ceratech could possibly tweak their formulation or retarder content of their activator to change these properties. For this reason, the authors suggest a trial batch to be performed whenever using this material.

Hardened Concrete Properties

Compressive Strength

The compressive strength properties for all mixtures are shown in Figure 1 to Figure 4 by increasing admixture dosage rate. Although, 11 of the 18 0.2 gal/cwt mixtures do not meet the minimum Department threshold for structural concrete at 4500 psi, the remaining mixtures do meet the minimum compressive strength. The compressive strength results show that the strength gain is dependent upon admixture content, as evidenced by the increasing strength as the admixture dosage rate increased up to 0.4 gal/cwt. The results show that increasing the fly ash content does not necessarily guarantee an increase in compressive strength, and this is consistent with traditional portland cement systems where water to cement ratio governs the strength significantly. A general trend can be noted showing that a lower w/a tends to lead to an increased strength.

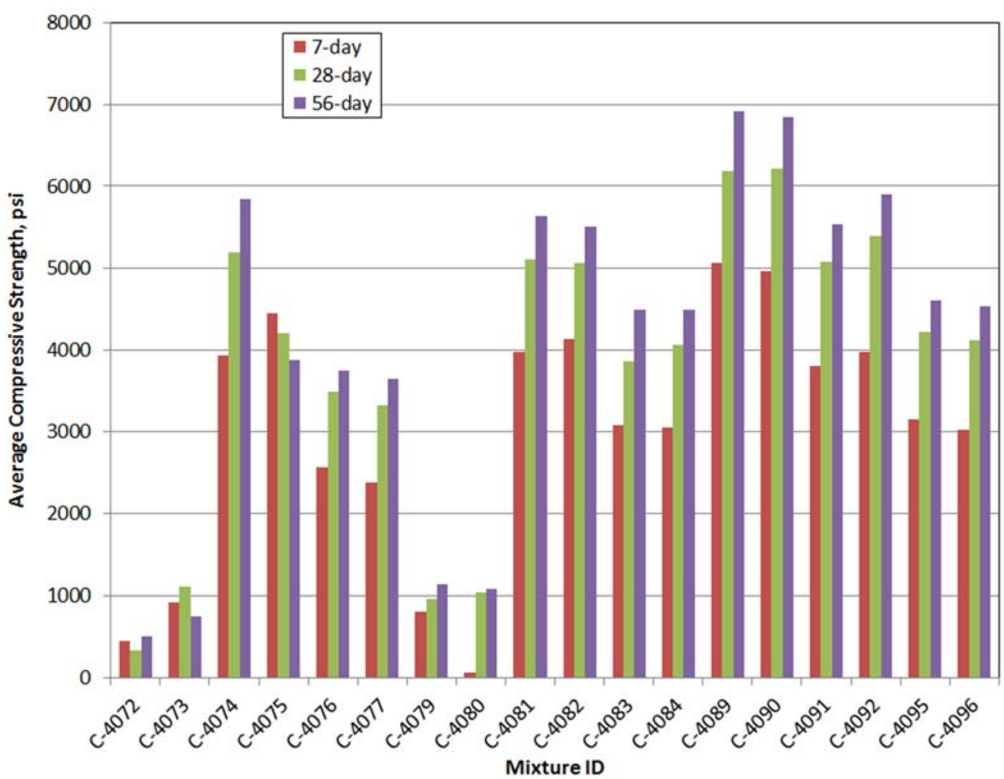

Figure 1
Average compressive strength results for the 0.2 gal/cwt mixtures

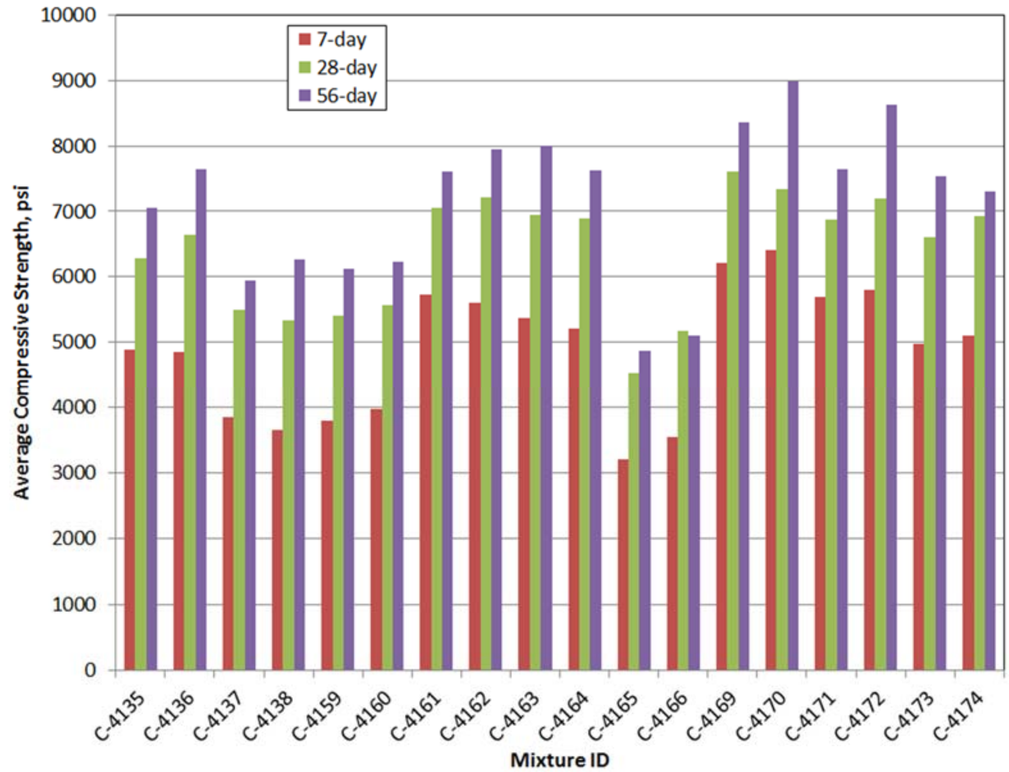

Figure 2
Average compressive strength for the 0.3 gal/cwt mixtures

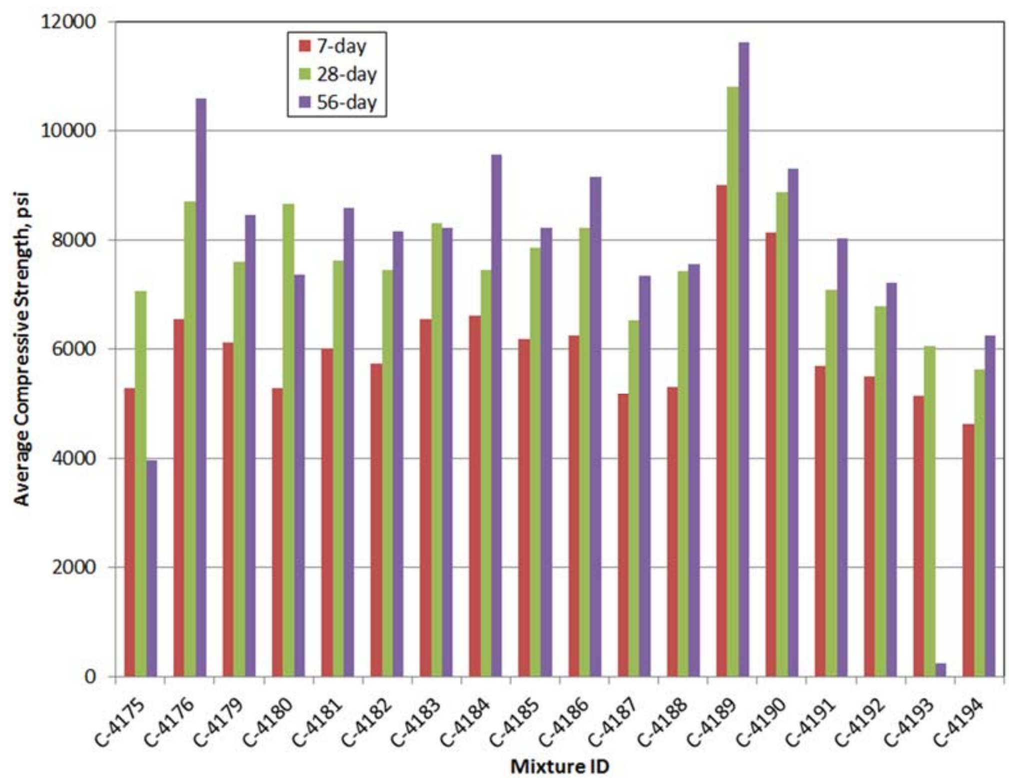

Figure 3
Average compressive strength for the 0.4 gal/cwt mixtures

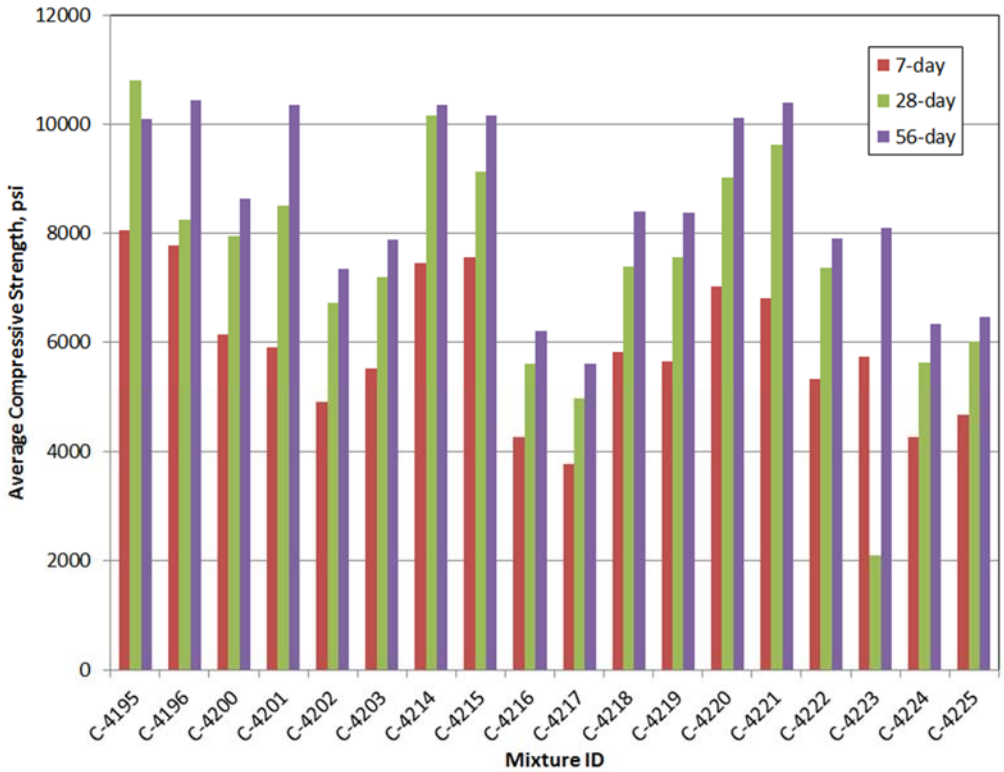

Figure 4
Average compressive strength for the 0.5 gal/cwt mixtures

Flexural Strength

The flexural strength results in Figure 5 to Figure 8 show an optimum dosage rate for flexural strength at about 0.4 gal/cwt of admixture. This is shown with increasing flexural strengths up to the dosage rate with limited gains at the 0.5 gal/cwt dosage rate. It is important to note that flexural strength gain from 7- to 56-days of age is not as significant as the compressive strength gains from 7- to 28-days of age for most mixtures.

The results in Figure 6 show the effect of ash content and water content well. The first six mixtures contain 600 pcy of ash produced at a w/a of 0.25, 0.30, and 0.35, respectively. As the w/a increases, the flexural strengths decrease as one would expect with a traditional portland cement system. The next six mixtures were produced with 700 pcy of ash and the strengths are generally higher for the same w/a. The last six mixtures were produced with 800 pcy ash at a w/a of 0.20, 0.25, and 0.30, respectively.

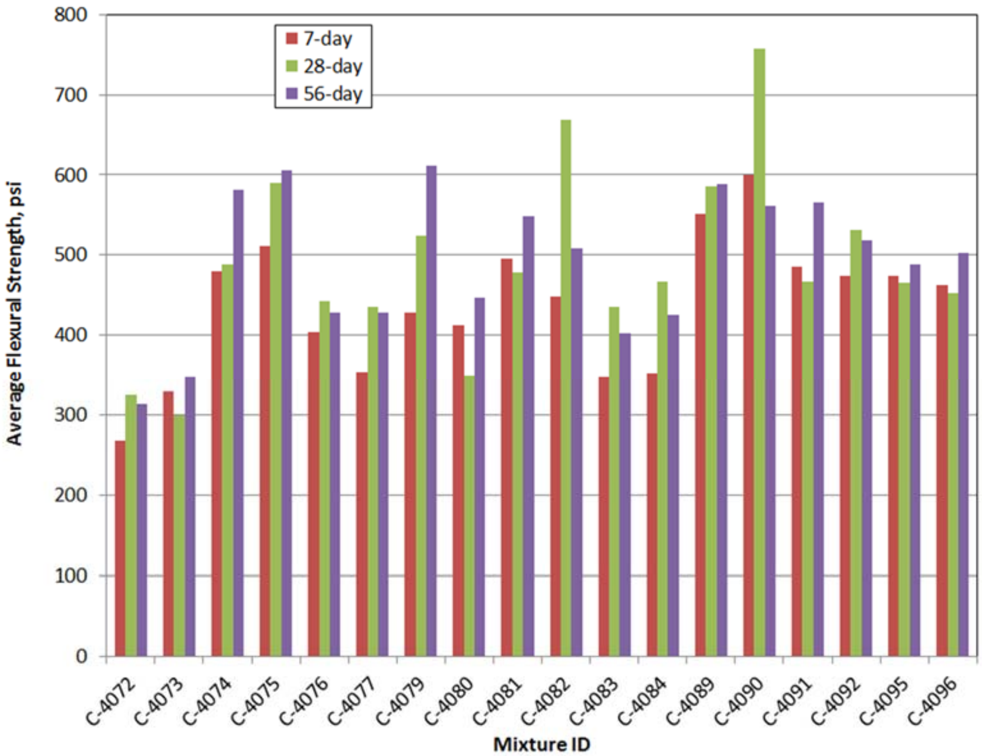

Figure 5
Average flexural strength for the 0.2 gal/cwt mixtures

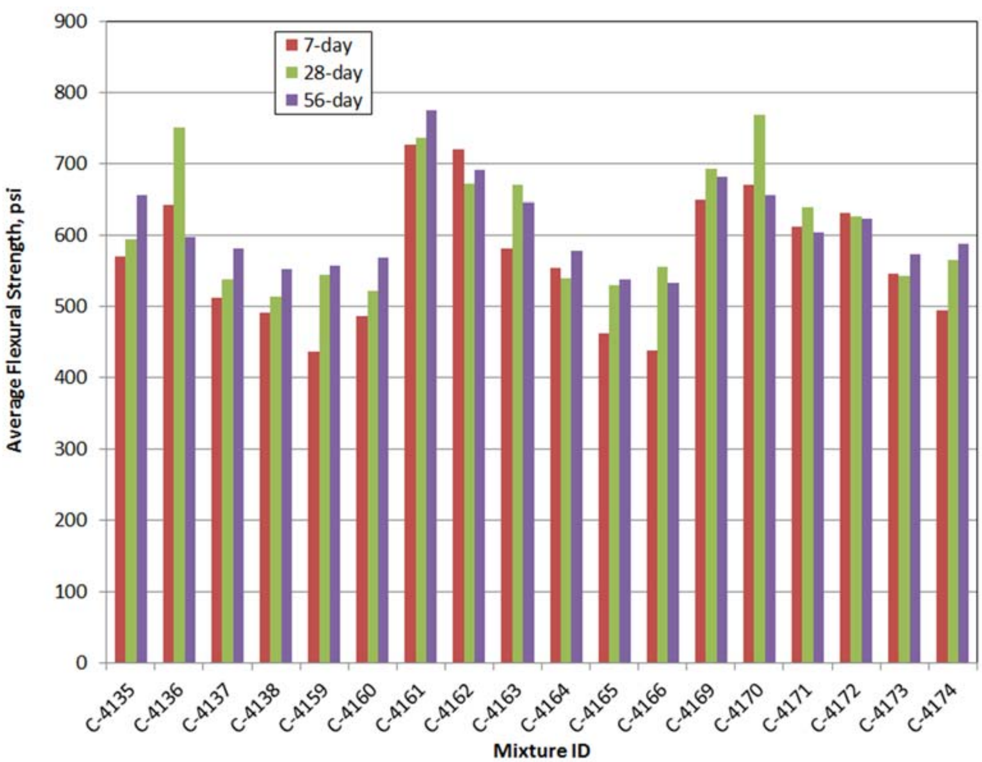

Figure 6
Average flexural strength for the 0.3 gal/cwt mixtures

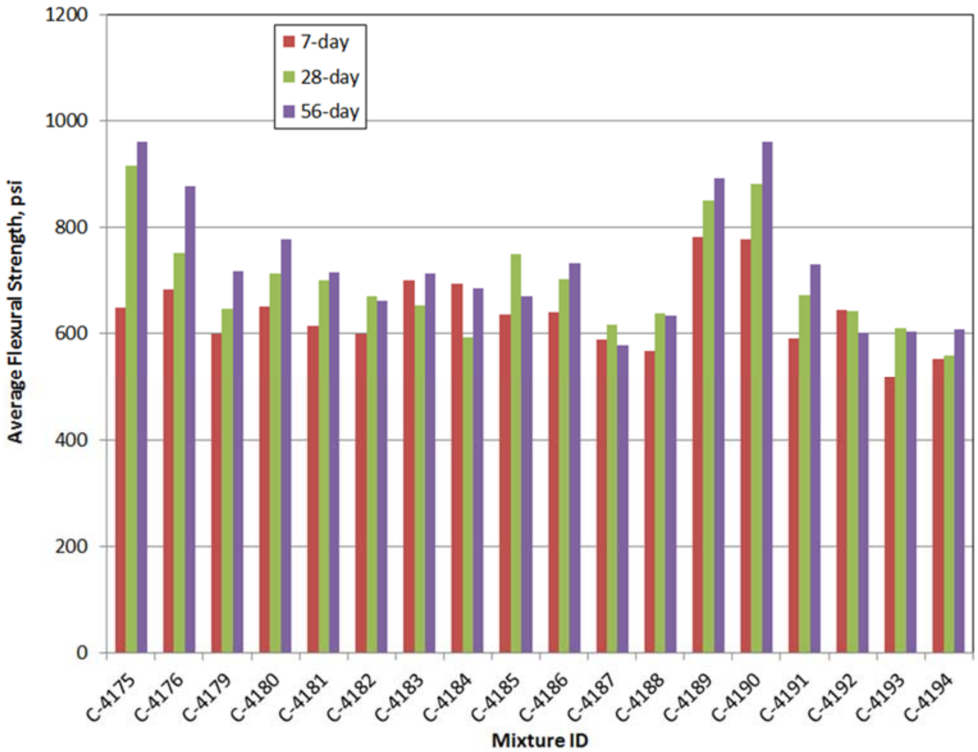

Figure 7
Average flexural strength for the 0.4 gal/cwt mixtures

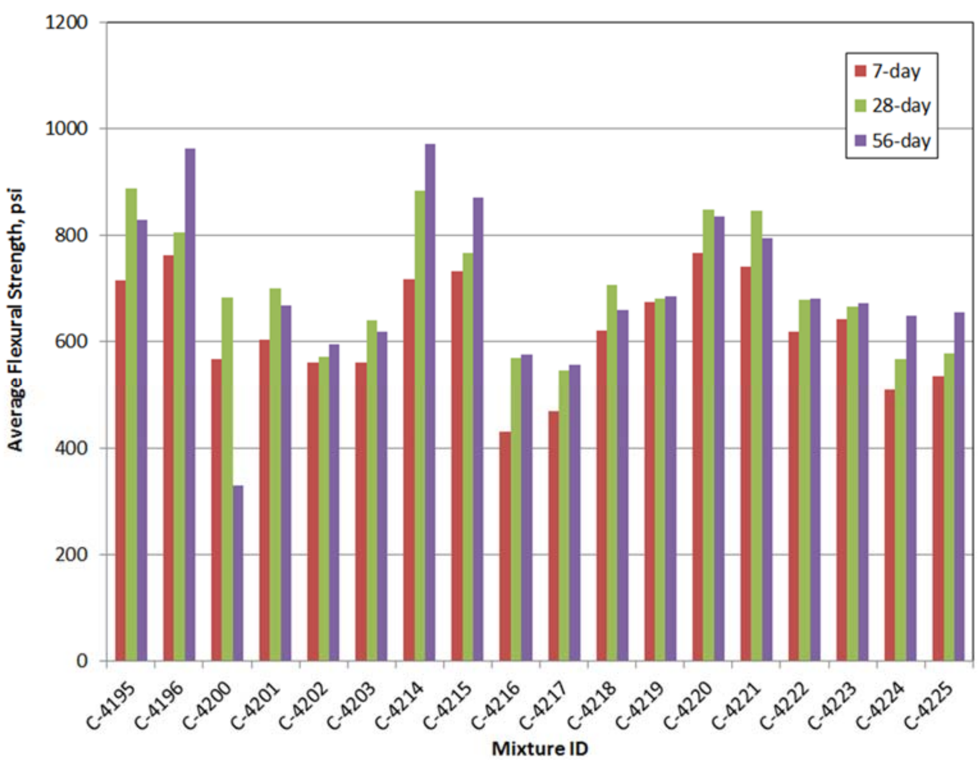

Figure 8
Average flexural strength for the 0.5 gal/cwt mixtures

Surface Resistivity

The surface resistivity results are shown in Figure 9 to Figure 12. Note that missing results indicate that the mixture was extremely honeycombed and the SR values were deemed to be unreliable to report. The results show that the surface resistivity test can be used to characterize this material. The 28-day surface resistivity values generally exceed the DOTD threshold of 22 kΩ-cm at 28-days of age once the admixture dosage is at, or above, 0.3 gal/cwt. The w/a effect is slight, but noticeable, especially in the 800 pcy ash content ranges. The increase in w/a ratio leads to a decrease in surface resistivity. This is common in traditional portland cement systems and stems from an increased amount of water in the system leaving larger pore spaces, which are more conductive to an electrical charge being passed through the sample (i.e., lower electrical resistance).

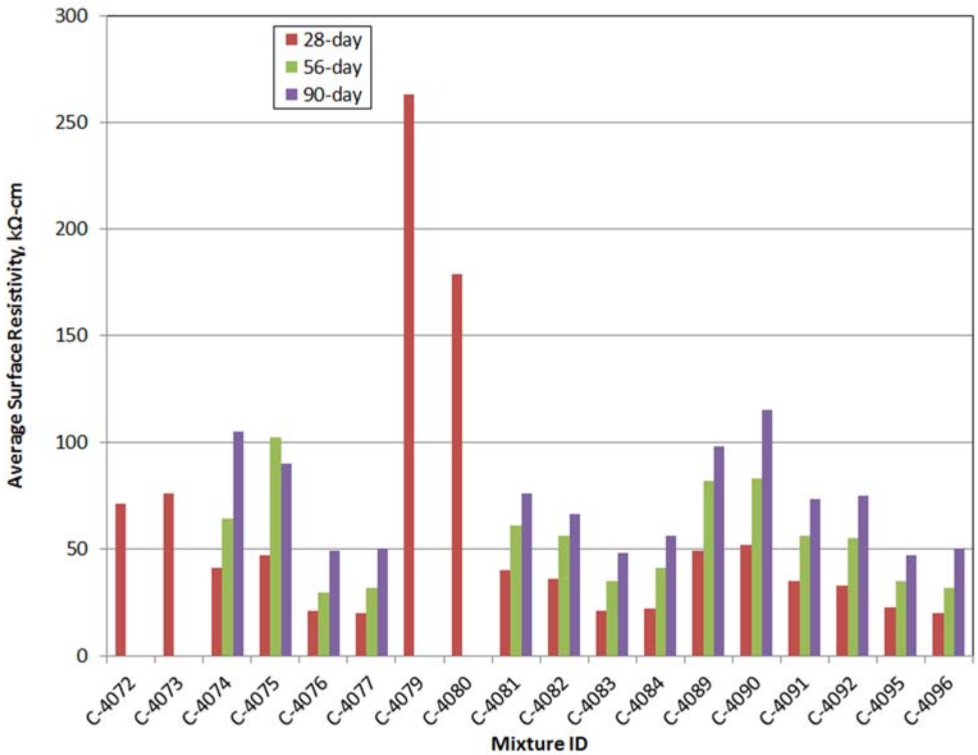

Figure 9
Average surface resistivity for the 0.2 gal/cwt mixtures

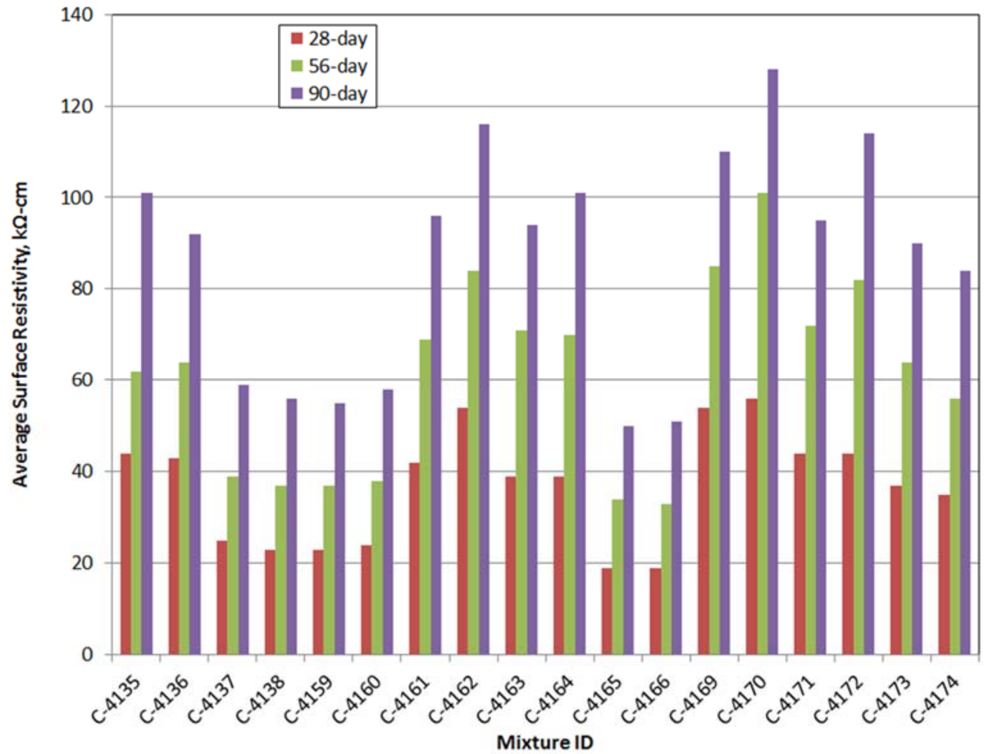

Figure 10
Average surface resistivity for the 0.3 gal/cwt mixtures

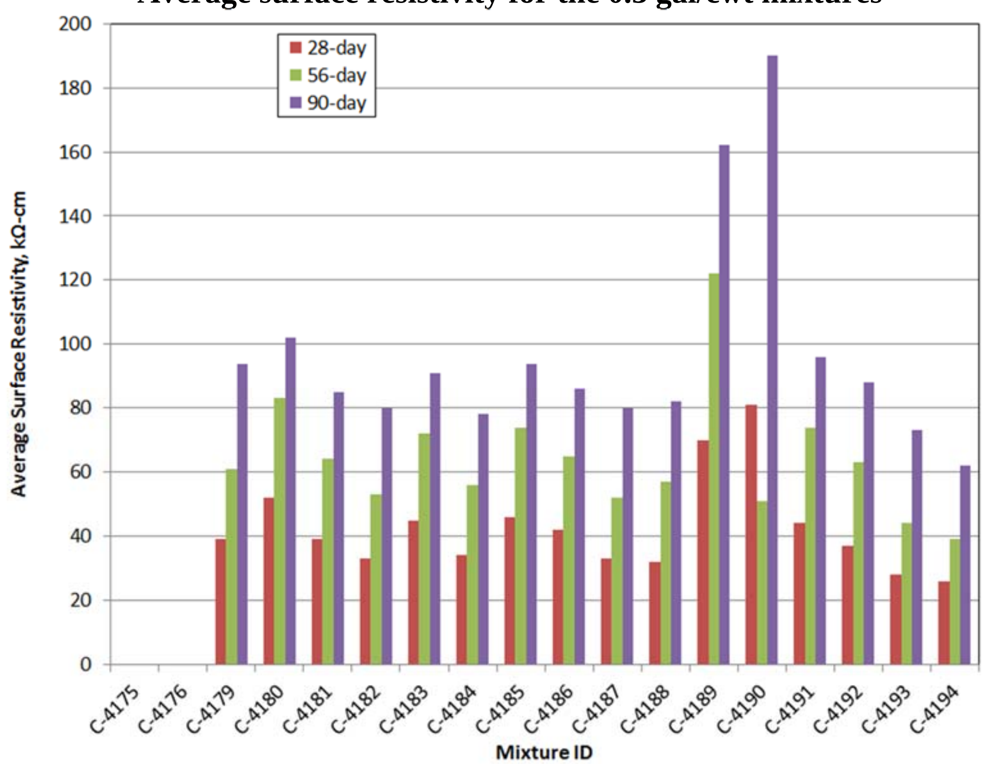

Figure 11
Average surface resistivity for the 0.4 gal/cwt mixtures

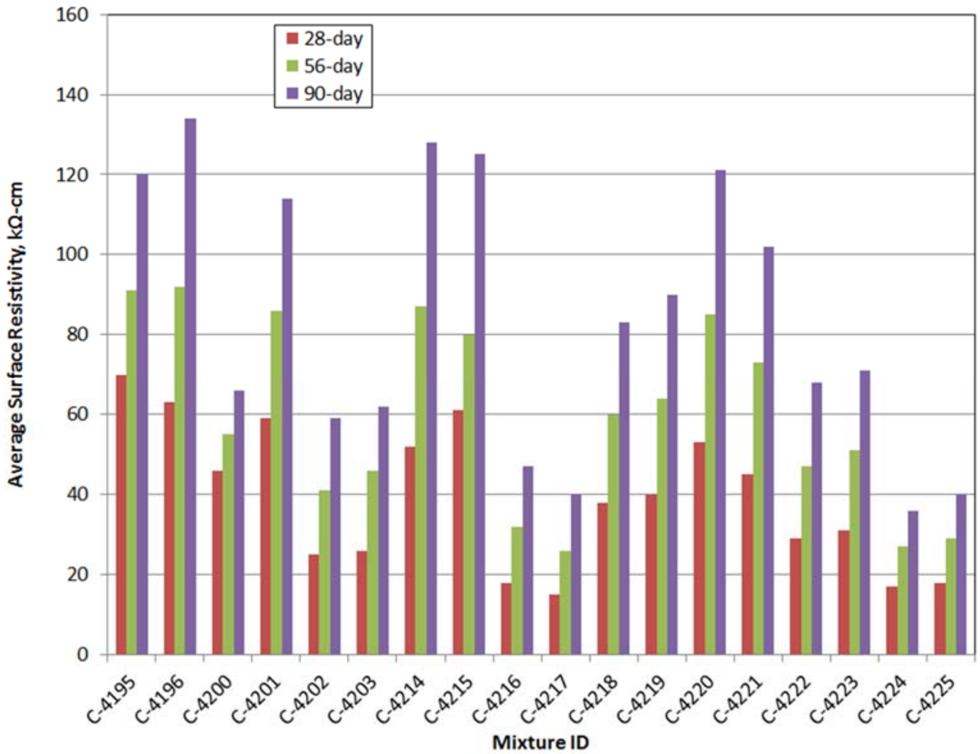

Figure 12
Average surface resistivity for the 0.5 gal/cwt mixtures

Length Change

The length change results are shown in Figure 13 to Figure 16. The results show that the length change for these mixtures is comparable or better than traditional portland cement concrete mixtures. The large movers (positive or negative) are considered outliers when looking at the replication data. If their replicate mixture did not move (shrink or expand), then the mixture result is considered an outlier. Figure 13 shows that the 0.2 gal/cwt mixtures performed well with a general movement of 0.01 percent.

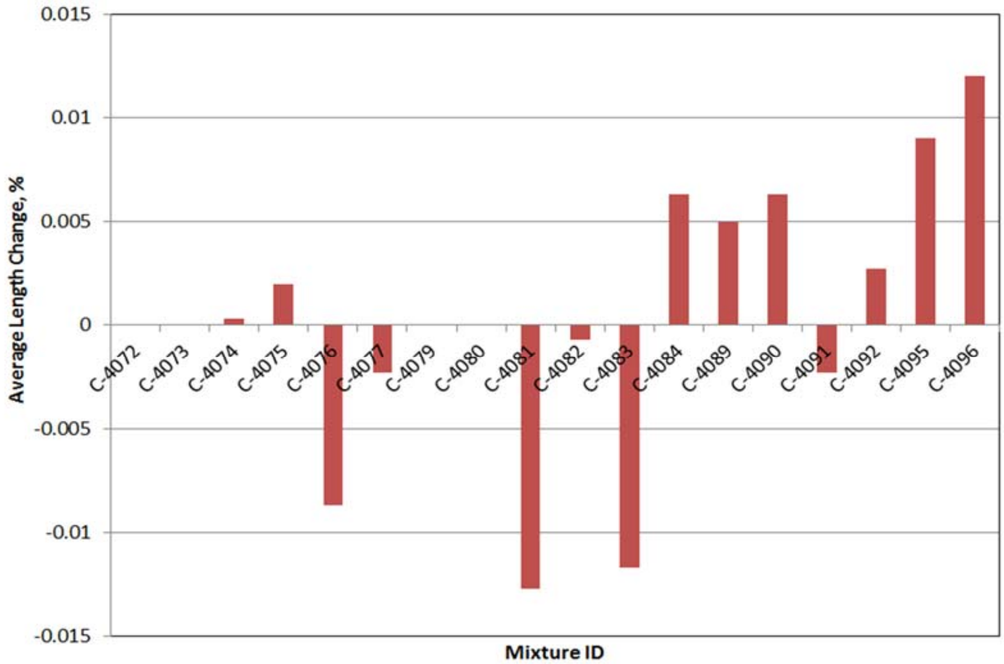

Figure 13
Average percent length change for the 0.2 gal/cwt mixtures

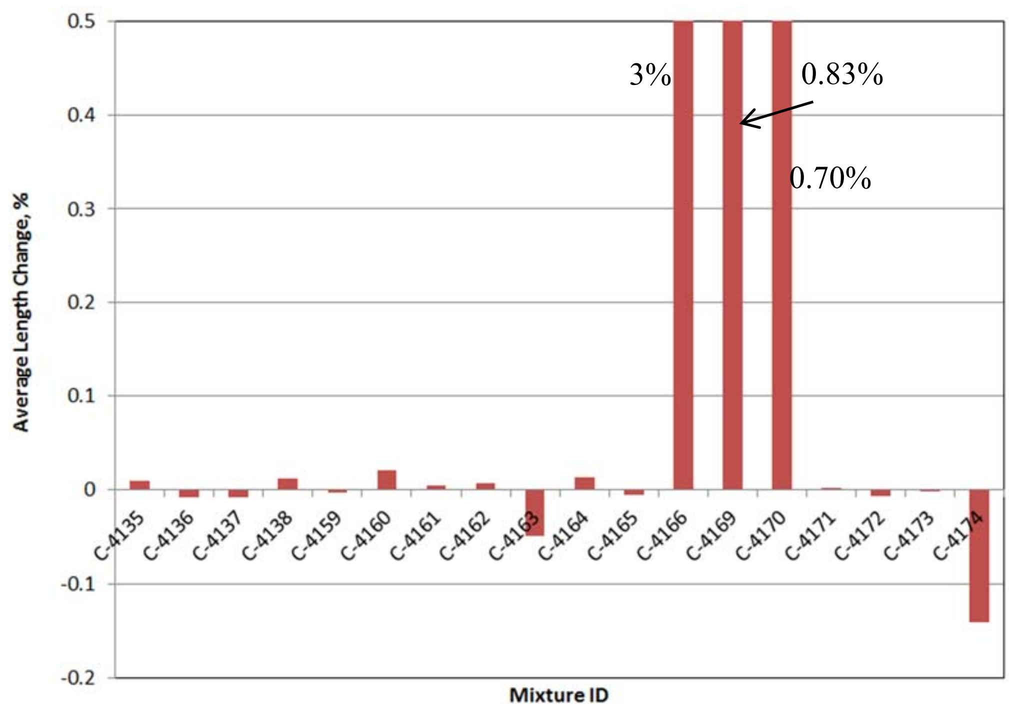

Figure 14
Average percent length change for the 0.3 gal/cwt mixtures

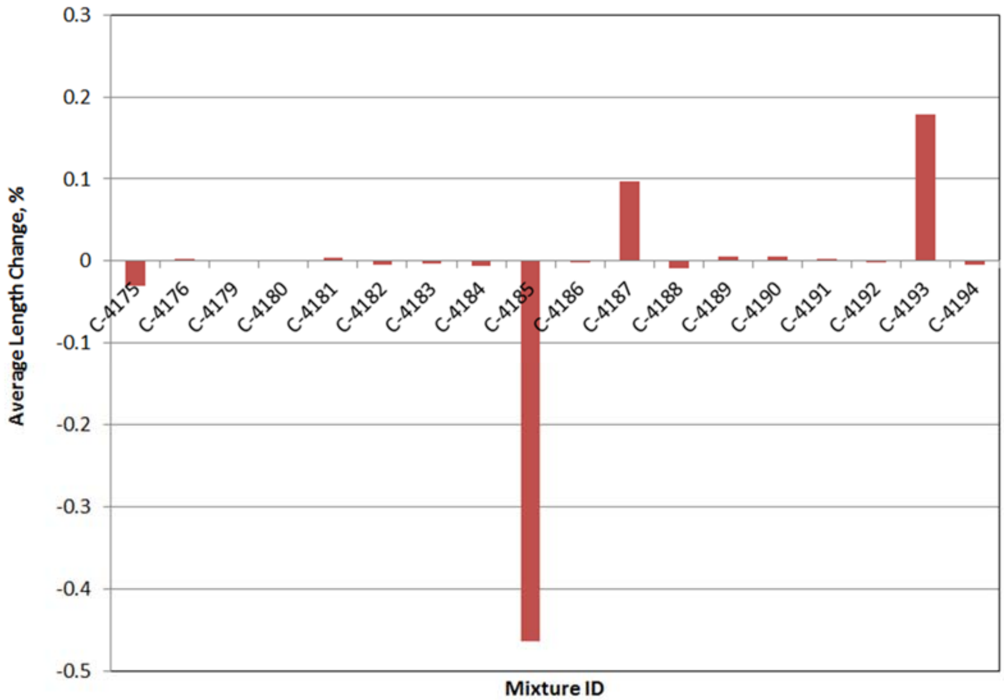

Figure 15
Average percent length change for the 0.4 gal/cwt mixtures

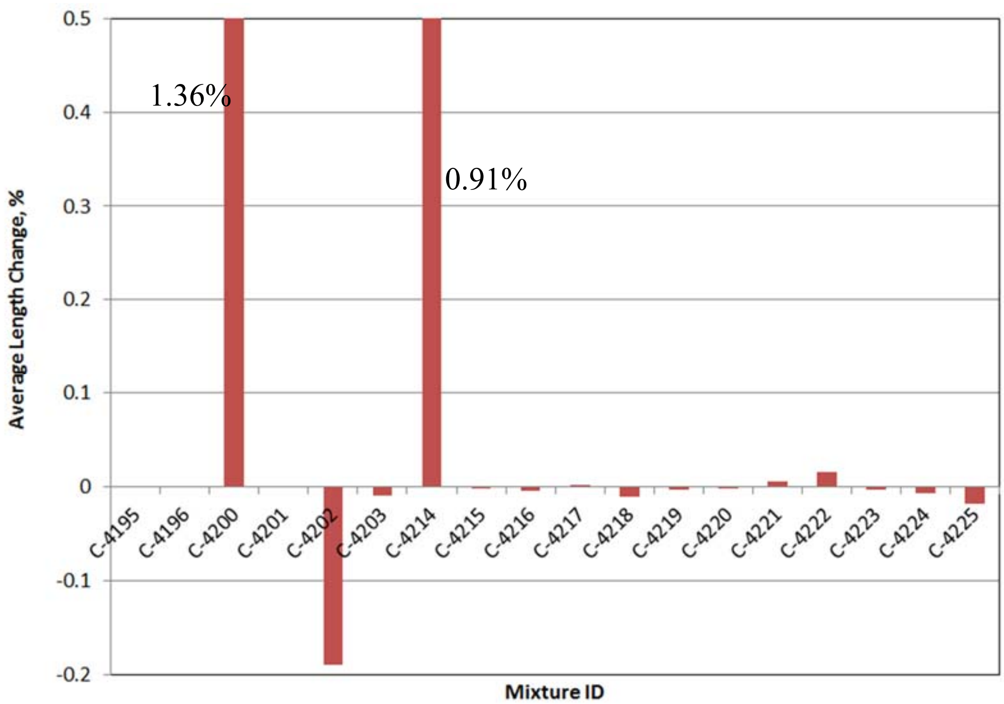

Figure 16
Average percent length change for the 0.5 gal/cwt mixtures

The hardened concrete properties show that many of the mixtures will meet or exceed DOTD requirements for compressive strength and surface resistivity. The results show that the overall strength is dependent upon admixture dosage rate, followed by the w/a and ash content, respectively. Although these mixtures will meet or exceed requirements, care should be exercised when utilizing this material; a trial batch is recommended for all applications. This is due to the short window between initial and final set time.

CONCLUSIONS

The results of this study warrant the following conclusions. The slump results show that the w/a ratio affect the slump greater than the admixture dosage rate. Generally the slump increases as dosage rate increases, but the trend is difficult to follow as the w/a changes between the different admixture dosage rates.

The time between initial and final set was very short. This is of concern to the authors due to the fact that this is the period in which the concrete material has to be finished and textured. In a controlled laboratory environment, this can be completed rather easily. In an ambient environment, many effects come into play such as wind speed, temperature, and relative humidity. The short window may be a barrier to full-scale implementation. Overdosing the admixture has a negative effect of producing concrete that does not set within a 24-hour time period, and sometimes not even within 36 hours.

The hardened concrete properties show that many of the mixtures will meet or exceed DOTD requirements for compressive strength and surface resistivity. The results show that the overall strength is dependent upon admixture dosage rate, followed by the w/a ratio and ash content, respectively. Although these mixtures will meet or exceed requirements, care should be exercised when utilizing this material; a trial batch is recommended for all applications.

RECOMMENDATIONS

The authors recommend that a discussion between the materials administrator, AML representatives for concrete materials, and the PRC be held to determine future usage of this product. Key points in the discussion will be to designate the product under the chemical admixture or cement designation(s).

ACRONYMS, ABBREVIATIONS, AND SYMBOLS

ASTM	American Society of Testing and Materials
DOT	Department of Transportation
DOTD	Louisiana Department of Transportation and Development
FHWA	Federal Highway Administration
ft.	feet
gal/cwt	gallons/hundred pounds of cementitous material
in.	inch(es)
LTRC	Louisiana Transportation Research Center
PCC	portland cement concrete
pcf	pounds per cubic foot
pcy	pounds per cubic yard
w/a	water to ash ratio
XRF	X-ray fluorescence

REFERENCES

1. Van Dam, T.J. "Geopolymer Concrete." *FHWA Tech Brief*. SHWA-HIF-10-014, Washington D.C., 2010.

2. Davidovits, J. "Geopolymer Chemistry and Applications." Institute Geopolymere, Saint-Quentin France, 2010.

3. ASTM C618. "Standard Specification for Coal Fly Ash and Raw or Calcined Natural Pozzolan for Use in Concrete." *Annual Book of ASTM Standards, Vol. 04.02*, ASTM, Philadelphia, PA, 2013.

4. Misra, A. "Stabilization Characteristics of Clays Using Class C Fly Ash." *Transportation Research Record 1611*, Transportation Research Board, Washington D.C., 1998.

5. Barnes, A. "Pavement Thickness Design Using Reclaimed Hydrated Iowa Class C Fly Ash as a Base Material." MSci Thesis, Iowa State University, Ames, IA, 1997.

6. Winkerton, H., and Pamukcu, S. "Soil Stabilization and Grouting." *Foundation Engineering Handbook, 2nd Edition*, New York, NY., 1991.

7. ASTM C138/138M. "Standard Test Method for Density (Unit Weight), Yield, and Air content (Gravimetric) of Concrete." *Annual Book of ASTM Standards,* Vol. 04.02, ASTM, Philadelphia, PA, 2013.

8. ASTM C231. "Standard Test Method for Air Content of Freshly Mixed Concrete by the Pressure Method." *Annual Book of ASTM Standards,* Vol. 04.02, ASTM, Philadelphia, PA, 2013.

9. ASTM C403/403M. "Standard Test Method for Time of Setting of Concrete Mixtures by Penetration Resistance." *Annual Book of ASTM Standards,* Vol. 04.02, ASTM, Philadelphia, PA, 2013.

10. ASTM C39. "Standard Test Method for Compressive Strength of Cylindrical concrete Specimens." *Annual Book of ASTM Standards,* Vol. 04.02, ASTM, Philadelphia, PA, 2013.

11. ASTM C78. "Standard Test Method for Flexural Strength of Concrete (Using Simple Beam with Third-Point Loading)." *Annual Book of ASTM Standards,* Vol. 04.02, ASTM, Philadelphia, PA, 2013.

12. ASTM C157/157M. “Standard Test Method for Length Change of Hardened Hydraulic-Cement Mortar and Concrete.” *Annual Book of ASTM Standards,* Vol. 04.02, ASTM, Philadelphia, PA, 2013.

13. DOTD TR 233-11. “Test Method for Surface Resistivity Indication of Concrete’s Ability to Resist Chloride Ion Penetration.” DOTD, Baton Rouge, LA, 2011.

This public document is published at a total cost of $250
42 copies of this public document were published in this first printing at a cost of $250. The total cost of all printings of this document including reprints is $250. This document was published by Louisiana Transportation Research Center to report and publish research findings as required in R.S. 48:105. This material was duplicated in accordance with standards for printing by state agencies established pursuant to R.S. 43:31. Printing of this material was purchased in accordance with the provisions of Title 43 of the Louisiana Revised Statutes.