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16. Abstract

Portland cement concrete (PCC) is the world's most versatile and most used construction materials. Global demand for PCC sustainability has risen as of late. To meet that need, engineers have looked to alternative binders such as fly ash, silica fume, ground granulated blast furnace slag (GGBFS), and other supplementary cementitous materials (SCMs) to increase pavement durability while lowering the initial and life-cycle cost.

Ternary mixtures were produced and the fresh and hardened characteristics were determined. Fresh concrete properties of air content, slump, unit weight, and set time were determined. Hardened concrete properties measured included: compressive strength, flexural strength, length change, coefficient of thermal expansion, modulus of elasticity, Poisson's ratio, rapid chloride permeability, and freeze-thaw durability.

Compressive strength results showed equal to or greater compressive strengths especially at later ages of 56 and 90 days. The compressive strengths of all mixtures with SCM replacements up to 80 percent met LADOTD specifications of 4000 psi. The ratios of the seven to 28 day compressive strengths showed that they are more resistant to early age cracking due to the lower modulus at early ages allowing for more creep. Flexural strengths of the ternary mixtures were generally greater than 650 psi with some reaching 1000 psi. These results show that the mixtures will prove adequate for most concrete paving applications, including interstate applications. The results also indicate that the pavement thickness may be reduced in some instances for certain traffic loading conditions. The length change, or shrinkage, results showed that the ternary mixtures performed the same of better than the control mixtures. This ensures that the risk of shrinkage cracking of properly mixed, placed, and cured ternary concrete mixtures is no greater than that of currently mixed, placed, and cured concrete mixtures. Additional curing may be required to prevent plastic shrinkage cracking. The rapid chloride permeability results show that the ternary mixtures will easily meet the new permeability specifications for all structural class concrete requiring less than 1500 Coulombs at 56 days or 27 kΩ-cm at 28 days of age. The CTE results show that addition of SCMs increase the CTE for certain mixtures, and decrease the CTE values for mixtures containing both class C and class F fly ash. The freeze-thaw results showed adequate freeze-thaw durability when the entrained air content was sufficient to prevent frost damage. The results point to an inadequacy in the ASTM standard for high SCM replacements in that the resulting concrete is usually not of sufficient strength to resist freeze-thaw damage at 14 days of age when the test is started. A change may need to be instituted for states where freeze-thaw damage is of concern where the concrete being tested is allowed to cure for a greater numbers of days before the onset of testing.

A portland cement replacement level with SCMs of about 70 percent for LADOTD concrete projects was determined to be reasonable. Care should be taken when interpreting these results and the results apply only to the materials used and tested through the course of this study. Producers and contractors wanting to implement these results are strongly encouraged to produce trail batches with their locally available materials to ensure the mixture's ability to meet and exceed the standards and specifications. The cost benefit ratio for implementation of the results may be as high as 21 depending upon the mixture used for construction and the number of cubic yards of concrete constructed in the state on any given year. Implementation of ternary mixtures will result in an estimated 62,000 tons of CO_2 saved for PCC pavements only and the number will be increased when accounting for structural concrete.

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Evaluation of Ternary Cementitious Combinations

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ABSTRACT

Portland cement concrete (PCC) is one of the world's most versatile and most used construction materials. To meet the rising demand for PCC sustainability, engineers have looked to alternative binders such as fly ash, silica fume, ground granulated blast furnace slag (GGBFS), and other supplementary cementitious materials (SCMs) to increase pavement durability while lowering initial and life-cycle costs.

Ternary mixtures were produced and the fresh and hardened characteristics were determined. Fresh concrete properties of air content, slump, unit weight, and set time were determined. Hardened concrete properties measured included: compressive strength, flexural strength, length change, coefficient of thermal expansion, modulus of elasticity, Poisson's ratio, rapid chloride permeability, and freeze-thaw durability.

Compressive strength results showed equal to or greater compressive strengths especially at later ages of 56 and 90 days. The compressive strengths of all mixtures with SCM replacements up to 80 percent met Louisiana Department of Transportation and Development (LADOTD) specifications of 4000 psi. The ratios of the 7 to 28 day compressive strengths showed that they are more resistant to early age cracking due to the lower modulus at early ages allowing for more creep.

Flexural strengths of the ternary mixtures were generally greater than 650 psi with some reaching 1000 psi. The results showed that the mixtures will prove adequate for most concrete paving applications, including interstate applications. The results also indicated that the pavement thickness may be reduced in some instances for certain traffic loading conditions.

The length change, or shrinkage, results showed that the ternary mixtures performed the same or better than the control mixtures. This ensures that the risk of shrinkage cracking of properly mixed, placed, and cured ternary concrete mixtures is no greater than that of currently mixed, placed, and cured concrete mixtures. Additional curing may be required to prevent plastic shrinkage cracking.

The rapid chloride permeability results showed that ternary mixtures will easily meet the new permeability specifications for all structural class concrete requiring less than 1500 Coulombs at 56 days or 27 kΩ-cm at 28 days of age.

The coefficient of thermal expansion (CTE) results showed that the CTE values increased slightly for some combinations of ternary mixtures while decreasing significantly for ternary

mixtures containing both class C and class F fly ash. A pavement design analysis will need to be completed to determine proper joint spacing.

The freeze-thaw results showed adequate freeze-thaw durability when the entrained air content was sufficient to prevent frost damage. The results point to an inadequacy in the ASTM standard for high SCM replacements in that the resulting concrete is usually not of sufficient strength to resist freeze-thaw damage at 14 days of age when the test is started. A change may need to be instituted for states where freeze-thaw damage is of concern where the concrete being tested is allowed to cure for a greater number of days before the onset of testing.

All the above results point to a reasonable portland cement replacement level with SCMs of about 70 percent for LADOTD concrete projects. Care should be taken when interpreting these results and the results apply only to the materials used and tested through the course of this study. Producers and contractors wanting to implement these results are strongly encouraged to produce trail batches with their locally available materials to ensure the mixture's ability to meet and exceed the standards and specifications.

The cost benefit ratio for implementation of the results may be as high as 21 depending upon the mixture used for construction and the number of cubic yards of concrete constructed in the state on any given year. Implementation of ternary mixtures will result in an estimated 62,000 tons of CO_2 saved for PCC pavements only and the number will increase when accounting for structural concrete.

ACKNOWLEDGMENTS

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IMPLEMENTATION STATEMENT

The author recommends implementation of ternary cementitious combinations for LADOTD projects. This recommendation extends to all classes of portland cement concrete used on LADOTD projects including precast, prestress, and pipe applications.

The following is a suggested specification. Allow up to 70 percent replacement for type I, II, and III portland cement. When using type IP or IS portland cement, allow up to 40 percent replacement. When using combinations of class C and class F fly ash, add them at the same rate. Do not add more fly ash than slag when using combinations of slag and fly ash.

The following contains suggested language for cold weather temperature limits when using ternary mixtures. Discontinue mixing and concreting operations when the descending air temperature away from artificial heat reaches 50°F or the forecast temperature to be less than 32°F for 48 hours. Do not resume mixing and concreting operations until an ascending air temperature in the shade and away from artificial heat reaches 32°F provided the high temperature forecasted is above 35°F and remains above 32°F for 48 hours.

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INTRODUCTION

PCC is one of the world's most versatile and most used construction materials. Modern concrete consists of six main ingredients: coarse aggregate, sand, portland cement, SCMs, chemical admixtures, and water. Because global demand for PCC sustainability has risen as of late, engineers have looked to alternative binders such as fly ash, silica fume, slag cement, and other SCMs to increase pavement durability while lowering the initial and life-cycle costs.

Ternary mixtures are uniquely suited to address the sustainability and cost aspect of PCC. There is general agreement that the use of SCMs has the following effects of concrete:

1. Improved workability and finish ability.
2. Strength gain – despite early strength reduction, beyond 7 days concrete incorporating SCMs tend to show increased strengths over portland cement concrete.
3. Effect of temperature rise in mass concrete – the use of SCMs has been shown to reduce early rate of heat generation.
4. Permeability is reduced in mature concrete and resistance to sulfate and chloride attack is improved.
5. Freeze thaw resistance, modulus of elasticity, and resistance to de-icing salts are all about the same as in ordinary portland cement concrete.
6. Resistance to corrosion of reinforcing steel – the use of SCMs in concrete helps to reduce permeability and thus reduces chloride ion penetration.
7. Increased time of setting and unpredictable change in time between initial and final set – this is of particular concern for saw cutting operations.

Literature Review

This section will give a brief literature review of previous work in the cementitious materials area. The various engineering properties of fresh and hardened concrete are detailed and the effects of SCMs on each are noted.

Detailed literature on the cementitious materials can be found in works published by the Portland Cement Association (PCA) and the National Concrete Pavement Technology Center [*1-2*]. A synthesis study detailing the use of ternary cementitious mixtures was conducted by the Canadian Cement Association; the results showed that the use of ternary mixtures was sporadic and was generally confined to particular Departments of Transportation (DOTs) [*3*]. Since the initial work completed by Tikalsky et al., a second phase has been completed and the results showed that replacements of portland cement up to 50 percent do not severely affect the PCC properties [*4*]. That study is currently finishing up the Phase III field trials in several states and is slated to be completed with a final report in late 2011.

OBJECTIVE

This research project set forth the following objectives: (1) characterize the fresh concrete properties of possible ternary combinations, and (2) characterize the hardened concrete properties of potential ternary combinations.

SCOPE

To meet the objectives, a test matrix was developed to characterize the fresh and hardened properties of ternary mixtures. The replacement rates for class C and class F fly ash were set at 0, 20, 30, and 40 percent. The replacement rates for grade 100 and grade 120 slags were set at 0, 30, and 50 percent. The control mixtures were produced using current replacement rates set forth in LADOTD specifications. The total replacement rate of type I/II portland cement varied from 20 to 90 percent.

METHODOLOGY

Test Methods

The following test methods were used to determine the respective characteristics of the mixtures and their constituents. Note that x-ray fluorescence (XRF) was used to determine the chemical characteristics for classification of the cementitious materials.

- ASTM C39 [Standard Test Method for Compressive Strength of Cylindrical Concrete Specimens] [*5*]
- ASTM C78 [Standard Test Method for Flexural Strength of Concrete (Using Simple Beam with Third-Point Loading)] [*6*]
- ASTM C136 [Standard Test Method for Sieve Analysis of Fine and Coarse Aggregates] [*7*]
- ASTM C138 [Standard Test Method for Density (Unit Weight), Yield, and Air Content (Gravimetric) of Concrete] [*8*]
- ASTM C143/143M [Standard Test Method for Slump of Hydraulic-Cement Concrete] [*9*]
- ASTM C150 [Standard Specification for Portland Cement] [*10*]
- ASTM C 157/157M [Standard Test Method for Length Change of Hardened Hydraulic-Cement Mortar and Concrete] [*11*]
- ASTM C231 [Standard Test Method for Air Content of Freshly Mixed Concrete by the Pressure Method] [*12*]
- ASTM C403/403M [Standard Test Method for Time of Setting of Concrete Mixtures by Penetration Resistance] [*13*]
- ASTM C469 [Standard Test Method for Static Modulus of Elasticity and Poisson's Ratio of Concrete in Compression] [*14*]
- ASTM C618 [Standard Specification for Coal Fly Ash and Raw or Calcined Natural Pozzolan for Use in Concrete] [*15*]

- ASTM C666 [Standard Test Method for Resistance of Concrete to Rapid Freezing and Thawing] [*16*]

- ASTM C989 [Standard Specification for Ground Granulated Blast-Furnace Slag for Use in Concrete and Mortars] [*17*]

- ASTM C1202 [Standard Test Method for Electrical Indication of Concrete's Ability to Resist Chloride Ion Penetration] [*18*]

The fresh concrete tests include slump, air, unit weight, and set time. Note that compressive strength specimens were cast in triplicate and tested at 7, 28, 56, and 90 days of age. Flexural strength specimens were cast in triplicate and tested at 7, 28, and 56 days of age. Freeze-thaw durability specimens were cast in triplicate. Rapid chloride permeability specimens were cast in duplicate and tested at 56 days of age. Length change and modulus of elasticity specimens were cast in duplicate and tested at 28 days of age and 7, 14, 28 and 90 days of age, respectively.

Test Matrix

The test matrix shown in Table 1 was developed to gain a greater understanding of the behavior of ternary mixtures, especially those with replacement rates greater than 50 percent. The mixture ID notes the name of each mixture, and the numbers in each of the columns indicate what percentage of that material is used. For example, Mixture ID 50TI-30G120S-20C contains 50 percent type I portland cement, 30 percent grade 120 slag, and 20 percent class C fly ash.

Each mixture was produced and cured at 70ºF. Concrete mixtures conformed to *Louisiana Standard Specifications for Roads and Bridges*. The reference mixture contained 500 lb. of total cementitious material per cubic yard, a #67 limestone coarse aggregate, and a natural sand fine aggregate. The coarse to fine aggregate ratio was set at 60:40 for the control mixtures. For ternary mixtures, the coarse aggregate was kept constant and the sand fraction was adjusted to keep a constant mortar volume for comparison of length change results. The water/cementitious material ration (w/cm) was kept constant at 0.45, and air entraining agents and water reducers were used to obtain mixtures conforming to LADOTD standards.

Table 1
Test matrix

Mixture ID	Type I/II PC	Class C FA	Class F FA	G100S	G120S
100TI*	100				
80TI-20C*	80	20			
80TI-20F*	80		20		
50TI-50G100S*	50			50	
50TI-50G120S*	50				50
50TI-30G120S-20C	50	20			30
40TI-30G120S-30C	40	30			30
30TI-30G120S-40C	30	40			30
30TI-50G120S-20C	30	20			50
20TI-50G120S-30C	20	30			50
10TI-50G120S-40C	10	40			50
50TI-30G100S-20C	50	20		30	
40TI-30G100S-30C	40	30		30	
30TI-30G100S-40C	30	40		30	
30TI-50G100S-20C	30	20		50	
20TI-50G100S-30C	20	30		50	
10TI-50G100S-40C	10	40		50	
50TI-30G120S-20F	50		20		30
40TI-30G120S-30F	40		30		30
30TI-30G120S-40F	30		40		30
30TI-50G120S-20F	30		20		50
20TI-50G120S-30F	20		30		50
10TI-50G120S-40F	10		40		50
50TI-30G100S-20F	50		20	30	
40TI-30G100S-30F	40		30	30	
30TI-30G100S-40F	30		40	30	
30TI-50G100S-20F	30		20	50	
20TI-50G100S-30F	20		30	50	
10TI-50G100S-40F	10		40	50	
60TI-20C-20F	60	20	20		
40TI-30C-30F	40	30	30		
20TI-40C-40F	20	40	40		

*Denotes a control mixture

Cost Benefit and Carbon Dioxide Footprint Analysis

A cost benefit analysis was conducted to estimate the value of implementing a change to the current specifications by allowing ternary cementitious combinations. For the purposes of this report, the cost to conduct the research was used as the cost factor and the benefit was determined using savings from bid data from paving projects. Table 2 shows the input parameters for the cementitious materials used in the cost benefit analysis. Note the difference in delivered cost of class C and class F fly ash and the difference in the delivered cost of grade 120 and grade 100 slag are negligible.

Table 2
Input parameters for the cementitious materials for the cost benefit analysis

Cementitious Material	Cost per Ton ($)
Portland Cement	$100.00
Fly Ash	$50.00
Slag	$90.00

A CO_2 footprint analysis was completed to estimate the tons of CO_2 emissions that may be saved due to implementing the results of this study. Table 3 shows the CO_2 amounts in tons of CO_2 emitted for each ton of material consumed. For purposes of this study, a value of 0.92 tons of CO_2 was assumed to be emitted per ton of portland cement produced. Fly ash was assumed to be zero, and 100 and 120 grade slag production contributes 0.15 and 0.20 tons of CO_2 per ton of slag produced, respectively.

Table 3
CO_2 load values for each cementitious material used in this study

Cementitious Material	CO_2 Load (Tons)
Portland Cement	0.92
Fly Ash	0.00
100 Grade Slag	0.15
120 Grade Slag	0.20

DISCUSSION OF RESULTS

Cementitious Materials Results

The x-ray fluorescence results show that the cementitious materials used in the study are representative of those used in everyday construction projects throughout the state of Louisiana and conform to applicable ASTM, AASHTO, and LADOTD standards and specifications. Table 4 shows the XRF results for the cementitious materials used in the laboratory test factorial. Note that all values are in percentage of the oxide.

Table 4
XRF results for the cementitious materials used in the laboratory test factorial

Oxide	Type I/II Portland Cement	Class C Fly Ash	Class F Fly Ash	Grade 100 Slag	Grade 120 Slag
SiO_2	20.24	35.04	60.74	38.59	34.77
Al_2O_3	4.45	19.30	19.41	7.61	10.73
Fe_2O_3	3.47	5.32	7.93	0.76	0.56
CaO	63.28	24.98	5.33	38.61	40.52
MgO	3.82	5.48	1.84	13.00	11.99
Na_2O	0.22	1.95	0.77	0.25	0.29
K_2O	0.44	0.46	1.19	0.38	0.38
TiO_2	0.28	1.36	1.01	0.36	0.60
SO_3	2.62	2.81	0.37	0.38	0.41
LOI	1.10	0.60	0.60	0.20	0.20

Fresh Concrete Property Results

This section will detail the fresh concrete properties for the ternary mixtures. Table 5 shows the fresh concrete properties of slump, air content, and unit weight for each mixture immediately after batching. Note that all mixtures met the slump and air content requirements set forth by LADOTD standards and specifications for portland cement concrete.

Table 5 also shows the time to initial and final set for each mixture. Note the increase in time to initial and final set as the percentage of portland cement is reduced. The extended set times are as expected with a steady increase up to between 70 and 80 percent replacement of portland cement. Above 80 percent portland cement replacement, the time to initial and final set were dramatically increased. The field results for these mixtures are expected to be slightly different due to the increased temperatures in summertime construction conditions. The author believes that for Louisiana environmental conditions, a portland cement replacement up to 70 percent will not be detrimental to performance and will actually aid contractors in the hot summer conditions.

Table 5
Fresh concrete property results for all mixtures

Mixture ID	Slump (in)	Air Content (%)	Unit Weight (pcf)	Time to Initial Set (hrs:mins)	Time to Final Set (hrs:mins)
100TI	2.25	4.5	147.4	4:47	6:13
80TI-20C	5.00	6.0	144.0	7:14	8:45
80TI-20F	5.00	5.8	144.0	5:50	7:23
50TI-50G100S	2.50	4.4	146.6	5:38	7:45
50TI-50G120S	4.00	5.1	144.2	5:34	7:51
50TI-30G120S-20C	1.00	3.2	149.2	5:28	7:24
40TI-30G120S-30C	1.50	3.3	148.8	7:58	10:20
30TI-30G120S-40C	1.00	3.4	149.2	8:36	12:16
30TI-50G120S-20C	2.00	3.6	148.4	7:02	9:46
20TI-50G120S-30C	3.00	3.5	146.8	9:35	12:47
10TI-50G120S-40C	4.00	2.9	148.8	8:33	11:49
50TI-30G100S-20C	5.00	5.2	143.4	5:55	8:13
40TI-30G100S-30C	3.25	4.7	144.4	6:04	8:18
30TI-30G100S-40C	6.75	4.3	147.0	10:21	13:13
30TI-50G100S-20C	4.25	3.5	146.4	7:57	10:57
20TI-50G100S-30C	3.00	3.9	145.6	9:27	13:04
10TI-50G100S-40C	3.50	2.7	147.0	10:53	19:33
50TI-30G120S-20F	2.50	3.6	147.8	6:06	8:13
40TI-30G120S-30F	1.50	2.9	147.6	6:15	8:59
30TI-30G120S-40F	3.25	4.0	146.6	8:12	11:17
30TI-50G120S-20F	1.50	3.7	147.8	8:02	11:23
20TI-50G120S-30F	0.50	4.4	145.6	8:16	13:49
10TI-50G120S-40F	7.50	3.4	145.6	15:25	30:27
50TI-30G100S-20F	2.75	3.9	147.6	6:29	8:43
40TI-30G100S-30F	5.25	3.8	148.0	7:01	9:23
30TI-30G100S-40F	6.00	5.8	147.4	7:34	11:28
30TI-50G100S-20F	0.00	2.8	148.8	4:59	8:35
20TI-50G100S-30F	0.50	2.6	149.2	5:17	9:29
10TI-50G100S-40F	0.75	2.8	147.4	7:40	16:20
60TI-20C-20F	5.50	5.1	144.4	9:31	11:34
40TI-30C-30F	6.00	5.4	143.2	11:35	15:05
20TI-40C-40F	8.50	4.2	144.0	13:25	37:10

Concrete produced with high replacement rates does have some drawbacks, especially when doing paving or flatwork. Research and experience shows that a higher rate of evaporation may occur during concrete placement and finishing; leading to an increased tendency for plastic shrinkage cracking. Extreme care must be taken to avoid plastic shrinkage cracking by good placement and curing practices. A double coat of curing compound may be required in certain circumstances.

Hardened Concrete Property Results

This section will detail the hardened concrete properties for the ternary mixtures. The results are presented as follows: compressive strength, flexural strength, modulus of elasticity, Poisson's ratio, permeability, coefficient of thermal expansion, length change, and freeze-thaw durability. The data presented are an average of test samples unless otherwise indicated. The individual sample results and raw data can be found in the Appendix.

Compressive Strength

The compressive strength results show that a wide range of ternary combinations will meet LADOTD compressive strength requirements. Figure 1 shows the comparison between compressive strength and age for the control mixtures. Note that these mixtures all meet the 4000 psi specification for structural concrete within seven days of age and the results are an average of thee cylinders.

Figure 2 shows the average compressive strength results for mixtures containing 100 grade slag and class C fly ash. Note that the only mixture not meeting the 4000 psi compressive strength at 28 days was the mixture containing only 10 percent portland cement. Although it did not meet at 28 days of age, the mixture passed compressive strength requirements at 56 days indicating that this mixture would be an ideal candidate for mass concrete placements with the least dimension being greater than 48 in. The results also indicated that the mixtures will continue to gain strength due to pozzolanic action based on the shape of the strength gain curves.

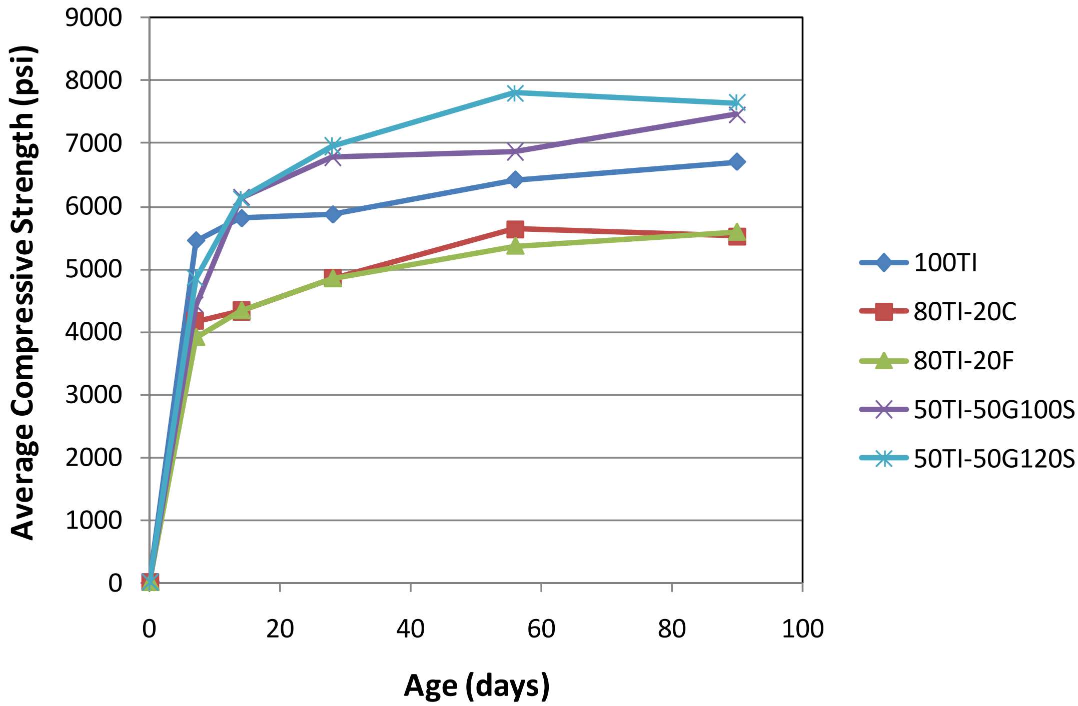

Figure 1
Average compressive strength results for the control mixtures

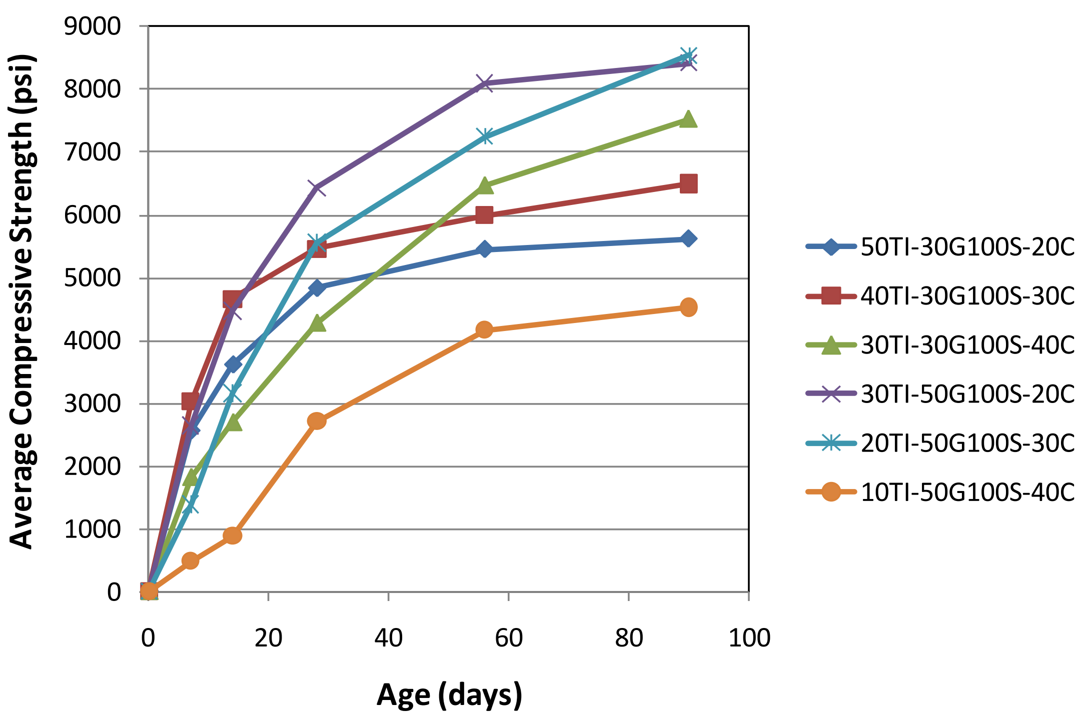

Figure 2
Average compressive strength results for mixtures containing 100 grade slag and class C fly ash

Figure 3 shows the average compressive strength results for mixtures containing 100 grade slag and class F fly ash. The only mixture not meeting the 4000 psi compressive strength at 28 days was the mixture containing only 10 percent portland cement. The remaining mixtures produced strengths exceeding 5000 psi at 90 days of age.

Figure 4 and Figure 5 show the average compressive strength results for mixtures containing 120 grade slag and class C and F fly ash, respectively. The results show that a replacement of portland cement up to 80 percent produced compressive strengths in excess of 4000 psi at 28 days of age. The 90 percent portland cement replacement mixtures still made 4000 psi, but at much later ages of 56 and 90 days for the mixtures containing class C and class F fly ash, respectively.

Figure 6 shows the average compressive strength results for mixtures containing both class C and class F fly ash. The results show that an increase in percentage of portland cement replacement greatly effects the compressive strengths at early ages. The results indicate that a maximum replacement rate for these mixtures is between 40 and 60 percent. Although these results are somewhat low for the laboratory, field results at 60 percent fly ash replacement have obtained over 5000 psi on a project located in Lake Charles, LA.

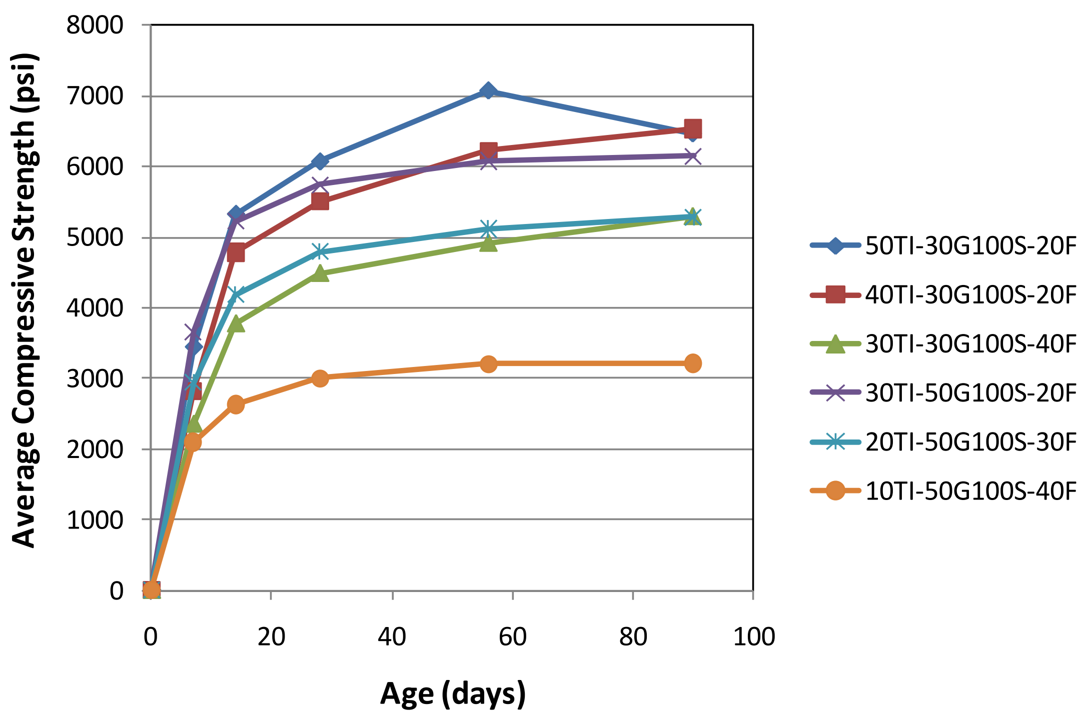

Figure 3
Average compressive strength results for mixtures containing 100 grade slag and class F fly ash

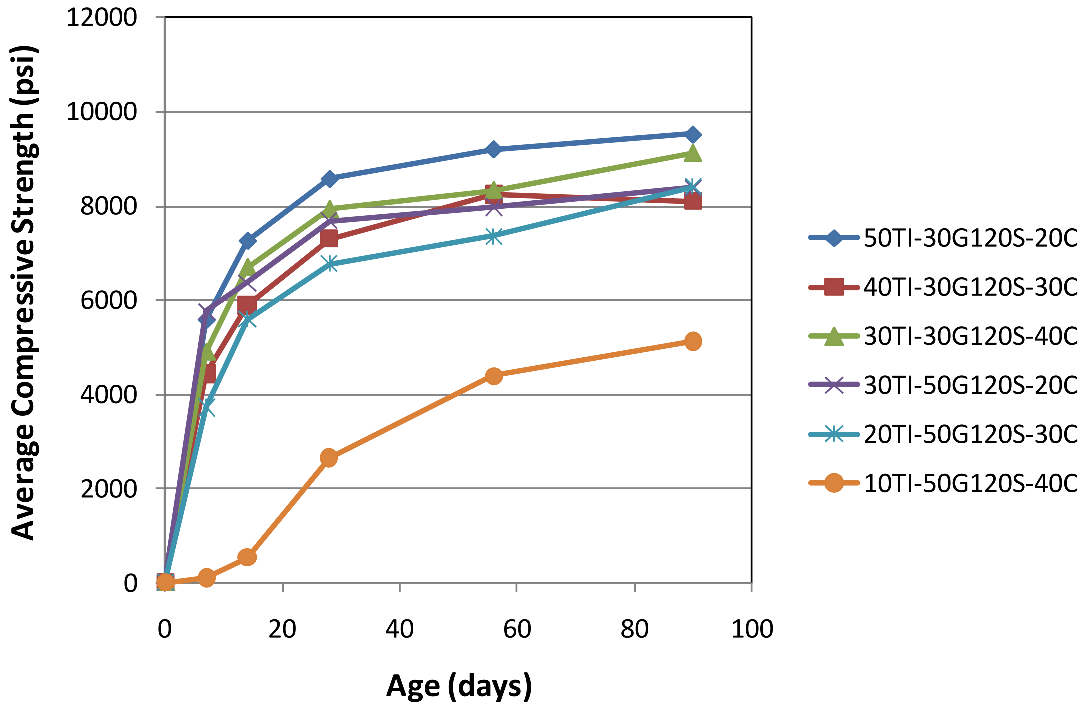

Figure 4
Average compressive strength results for mixtures containing 120 grade slag and class C fly ash

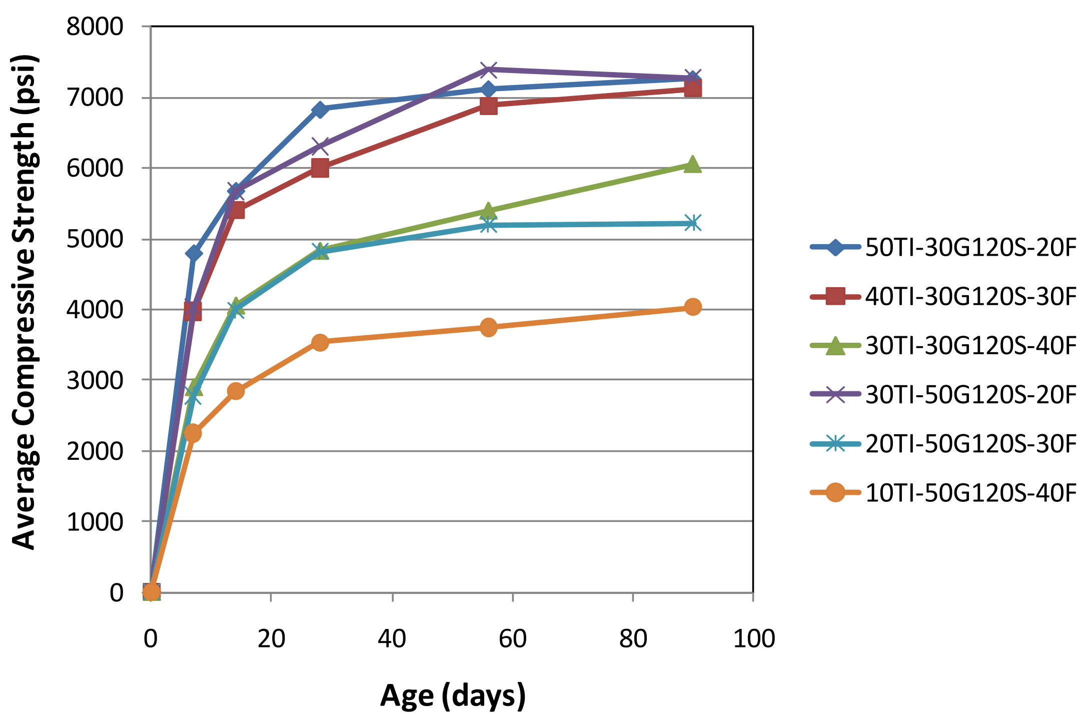

Figure 5
Average compressive strength results for mixtures containing grade 120 slag and class F fly ash

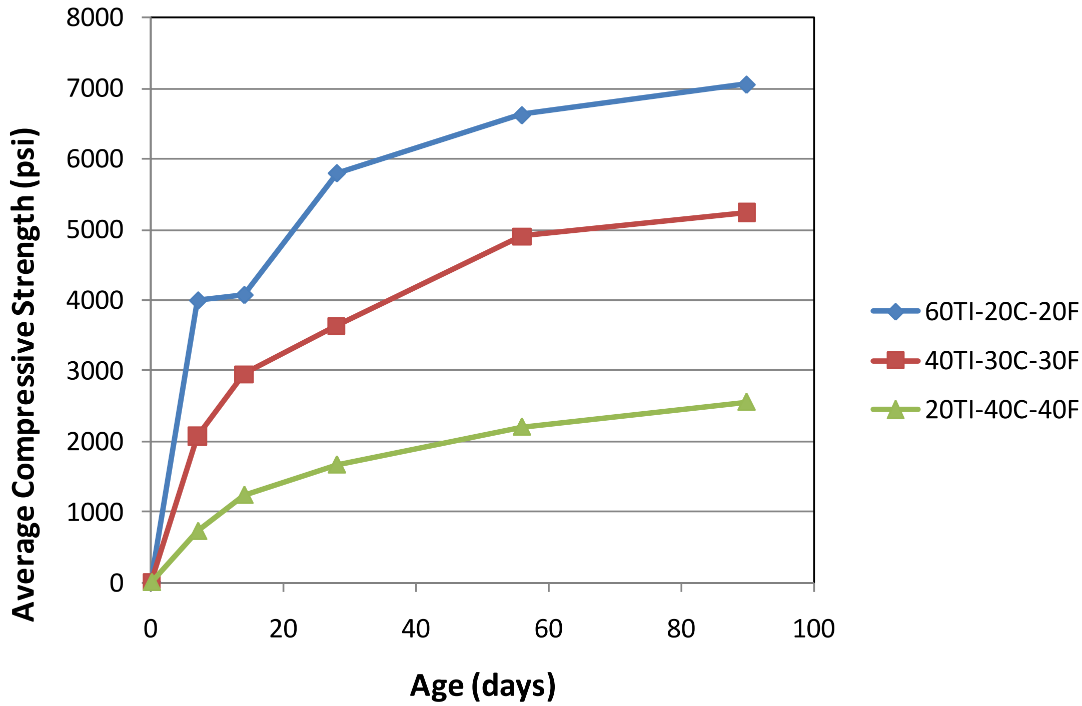

Figure 6
Average compressive strength resutls for mixtures containing class C and class F fly ash

The compressive strength results are very encouraging and indicate that up to 80 percent of the portland cement can be replaced for a large portion of concrete mixtures used on LADOTD projects. The results showed that LADOTD has been very conservative with only allowing up to 20 to 30 percent fly ash and up to 50 percent GGBFS in binary mixtures.

Table 6 shows the average 7- and 28-day compressive strengths and the ratio between the two. The portland cement control mixture had a ratio of about one. This indicates that nearly all the strength is being gained within the first seven days after batching and placement. The binary fly ash mixtures had a ratio of 1.17 and 1.24 for the class C and class F fly ash combinations, respectively. These values are still very typical being under 1.5. Note that the binary mixtures containing slag had ratios 1.43 and 1.53.

The 28- to 7-day compressive strength ratios for the ternary mixtures are significantly different. The lowest ratio for a ternary mixture is 1.40 and the highest is 25.49. These values indicate that the concrete mix design is a slower strength gain. One advantage of a slower strength gain is the concrete has a lower modulus value at early ages allowing for more creep. This increased ability to creep at early ages can lead to a reduction in cracking potential.

The main drawbacks to lower early age strengths are the need to keep forms in place longer for structural concrete applications and an increased time to initial set for sawing operations to begin for paving applications. These problems are easily addressed with an adjustment in paving and sawing operations for paving concrete and the introduction of another set of forms, or leave-in-place forms for structural concrete applications. Additional curing may be required to prevent plastic shrinkage cracking. Set accelerating admixtures may be used to shorten the time to initial set for sawing operations, or early removal of forms.

Table 6
Average 7- and 28-day compressive strengths and the 28- to 7-day compressive strength ratio for all mixtures

Mixture ID	7 Day	28 Day	28:7
100TI	5446	5860	1.08
80TI-20C	4165	4857	1.17
80TI-20F	3907	4842	1.24
50TI-50G100S	4421	6785	1.53
50TI-50G120S	4855	6956	1.43
50TI-30G100S-20C	2560	4832	1.89
40TI-30G100S-30C	3024	5465	1.81
30TI-30G100S-40C	1821	4284	2.35
30TI-50G100S-20C	2643	6430	2.43
20TI-50G100S-30C	1390	5559	4.00
10TI-50G100S-40C	490	2716	5.54
50TI-30G100S-20F	3444	6071	1.76
40TI-30G100S-20F	2830	5508	1.95
30TI-30G100S-40F	2356	4494	1.91
30TI-50G100S-20F	3664	5748	1.57
20TI-50G100S-30F	2940	4796	1.63
10TI-50G100S-40F	2096	3006	1.43
50TI-30G120S-20C	5587	8582	1.54
40TI-30G120S-30C	4436	7306	1.65
30TI-30G120S-40C	4900	7931	1.62
30TI-50G120S-20C	5757	7687	1.34
20TI-50G120S-30C	3718	6780	1.82
10TI-50G120S-40C	104	2651	25.49
50TI-30G120S-20F	4797	6832	1.42
40TI-30G120S-30F	3975	6009	1.51
30TI-30G120S-40F	2901	4831	1.67
30TI-50G120S-20F	4034	6314	1.57
20TI-50G120S-30F	2783	4826	1.73
10TI-50G120S-40F	2252	3537	1.57
60TI-20C-20F	3998	5807	1.45
40TI-30C-30F	2072	3636	1.75
20TI-40C-40F	725	1669	2.30

Flexural Strength

The flexural strength results are shown in Figure 7 to Figure 12. The results in Figure 8 to Figure 12 show that the ternary mixtures performed equal to or better than the control mixtures. A significant target value for LADOTD projects is equal to or greater than 650 psi. The control mixtures are meeting that value in three days while the ternary mixtures are delayed until 14 or 28 days of age. This reduction in early age flexural strength will require contractors to keep traffic off the completed roadway for a slightly longer period.

Many of the ternary mixtures exhibited flexural strengths greater than 800 psi. These strengths are significant when designing a pavement using the mechanistic empirical pavement design guide (MEPDG). Increased flexural strengths will lead to reductions in the required pavement thickness to withstand a given traffic loading. This reduction in thickness, if realized, will lead to more cost effective concrete pavement roadway sections.

The 90 percent replacement mixtures showed greatly reduced flexural strengths compared to other ternary mixtures and the control mixtures. This shows that these mixtures will most likely be inadequate in normal everyday concrete applications for LADOTD. It is important to note that these mixtures may have significant purpose in very large mass concreting applications such as large footings or drilled shafts.

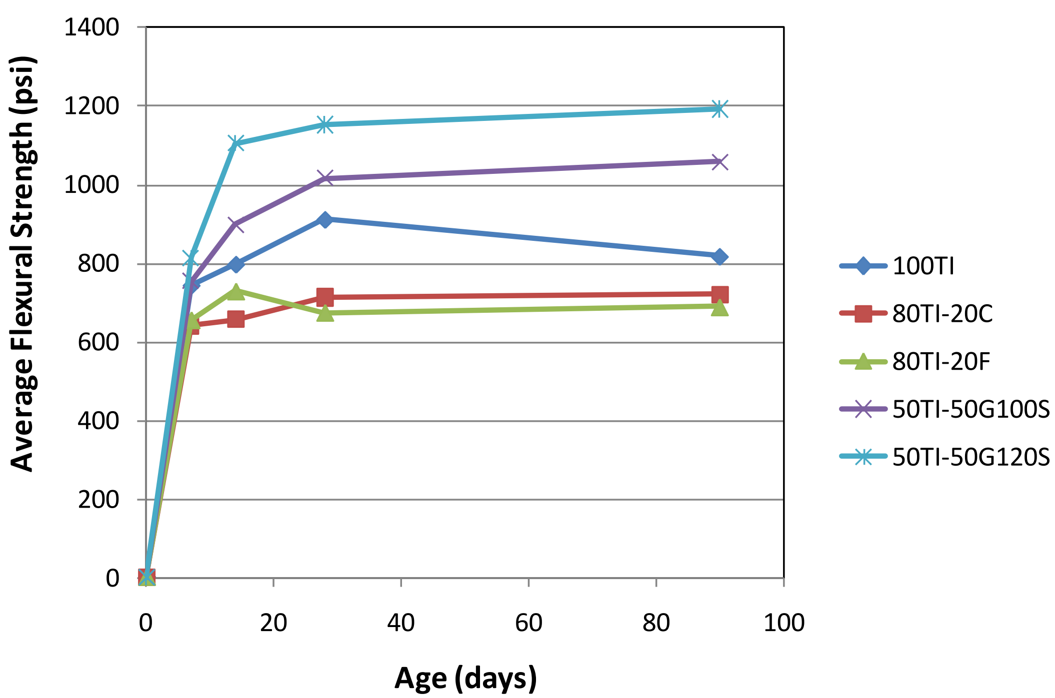

Figure 7
Average flexural strength results for the control mixtures

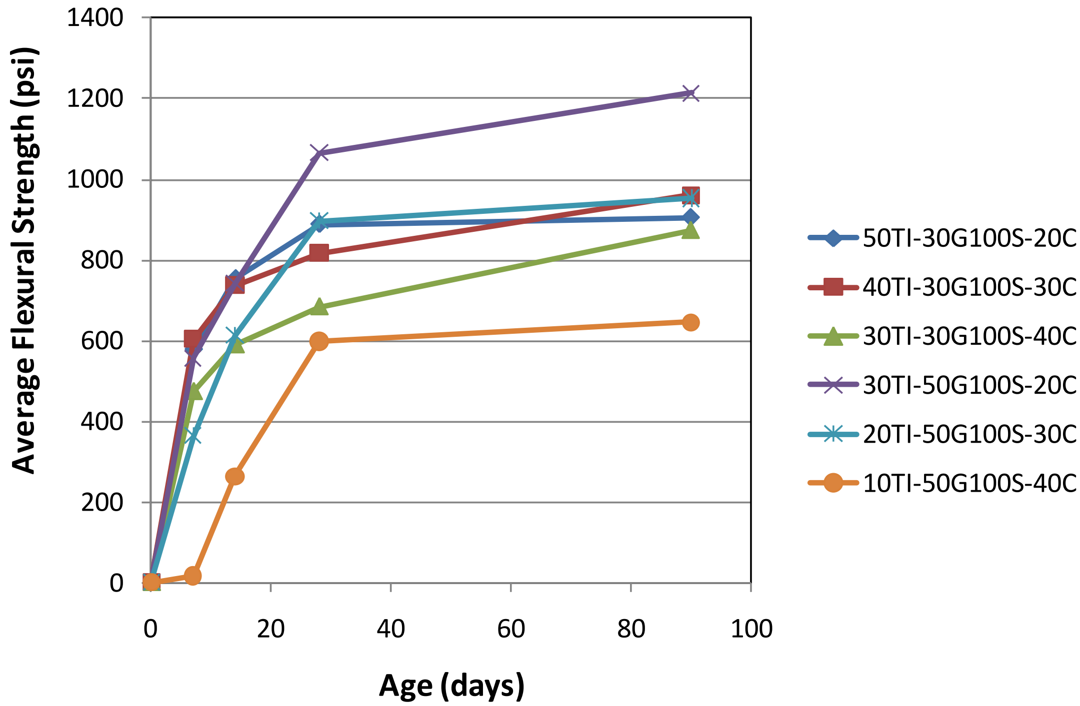

Figure 8
Average flexural strength results for mixtures containing grade 100 slag and class C fly ash

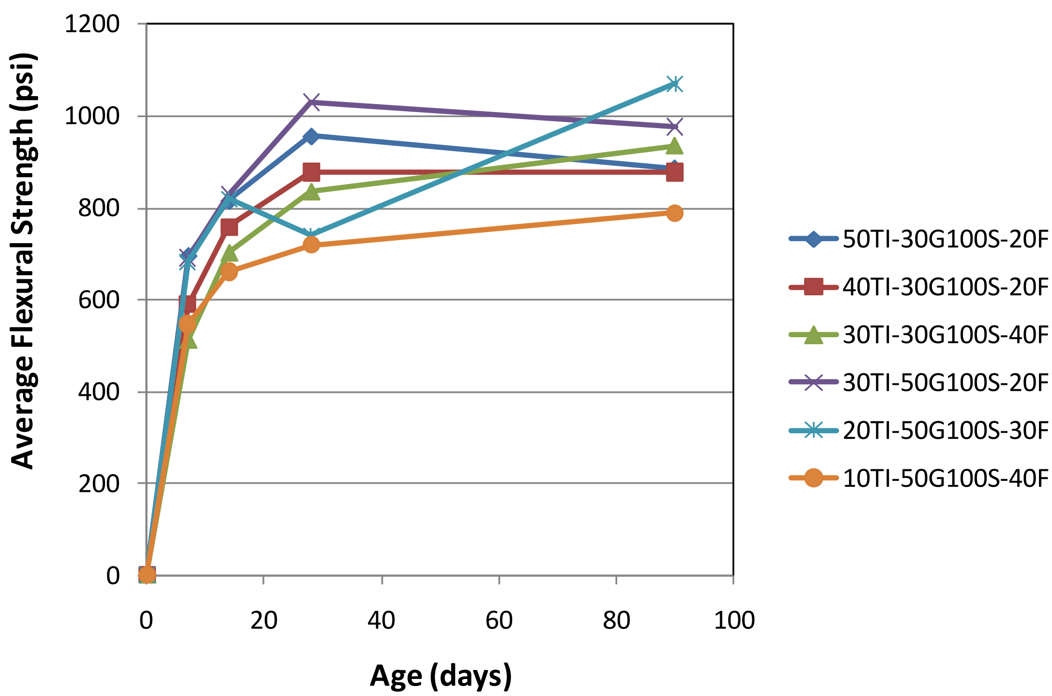

Figure 9
Average flexural strength results for mixtures containing grade 100 slag and class F fly ash

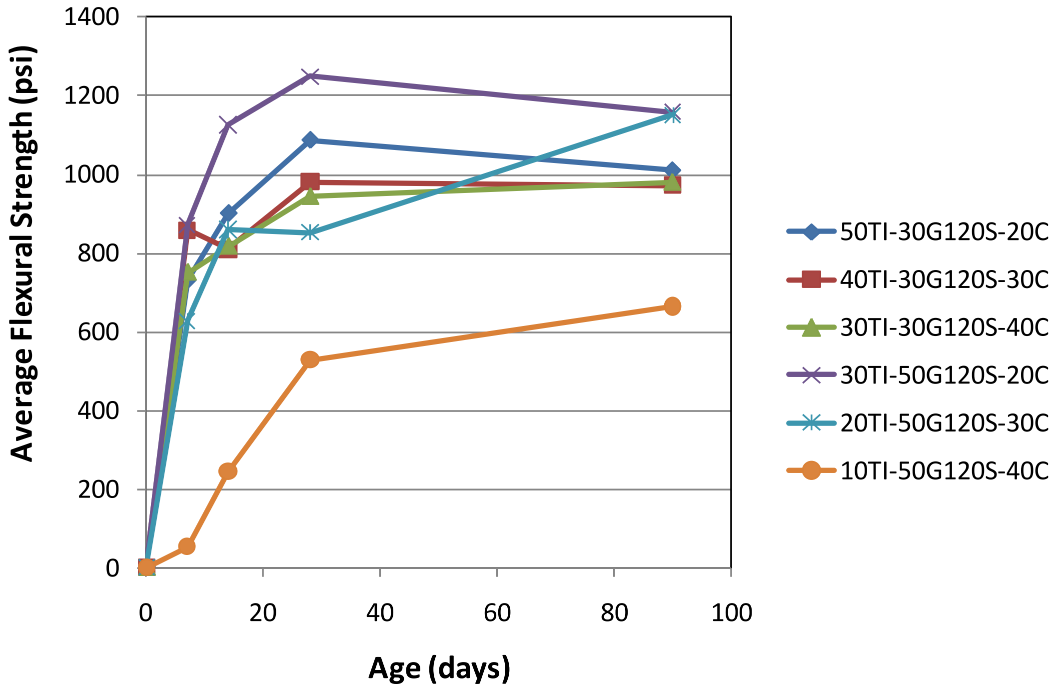

Figure 10
Average flexural strength results for mixtures containing grade 120 slag and class C fly ash

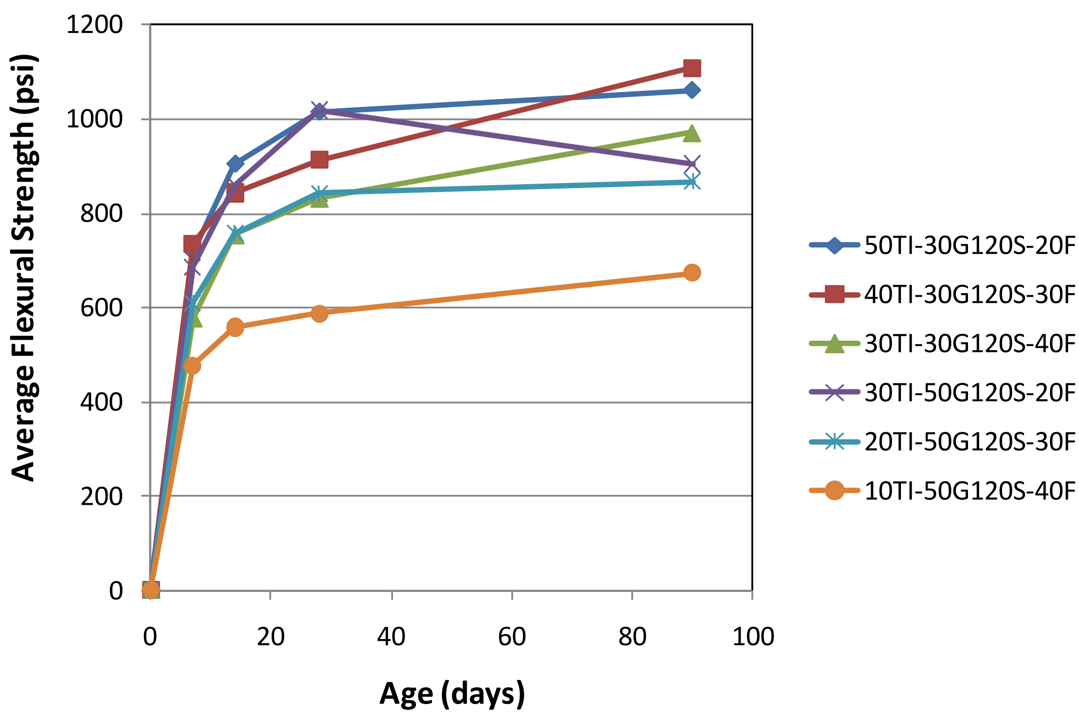

Figure 11
Average flexural strength resutls for mixtures containing grade 120 slag and class F fly ash

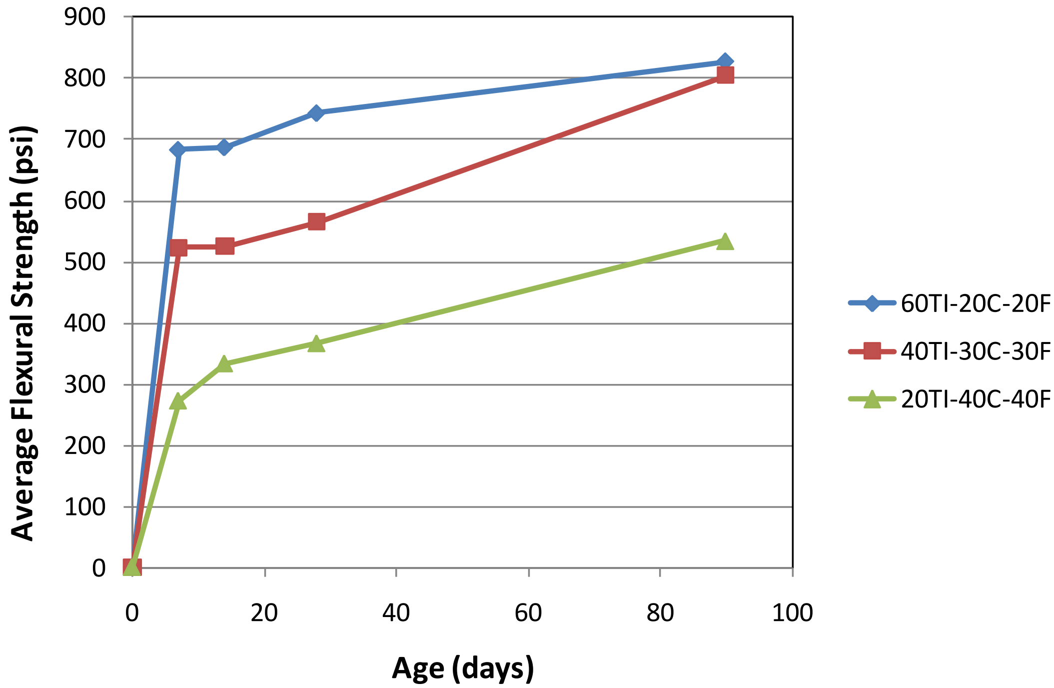

Figure 12
Average flexural strength results for mixtures containing class C and class F fly ash

Modulus of Elasticity and Poisson's Ratio

Table 7 shows the modulus of elasticity results for all mixtures at various ages. Table 8 shows the results for Poisson's ratio for all mixtures at various ages. The results are as expected with the ternary mixtures showing slightly lower results at 28 days of age. The lower results are due to the increased SCM content and those SCMs not being fully hydrated at 28 days of age. The 90-day results for the ternary mixtures are nearly equal to the control mixtures. The 28-day results for the ternary mixtures fall within the expected 4-6 million psi range for portland cement concrete. Note that the "N/A" for a particular day indicates that no samples were tested for that age due to samples being broken during the process of de-molding.

Table 7
Average modulus of elasticity results for all mixtures

	Modulus of Elasticity (psi)			
Mixture ID	**7 Day**	**14 Day**	**28 Day**	**90 Day**
100TI	4895000	5000000	5300000	5600000
80TI-20C	4200000	4175000	4525000	5225000
80TI-20F	4350000	4400000	4875000	5025000
50TI-50G100S	4400000	5100000	5225000	5450000
50TI-50G120S	4575000	4625000	5025000	5825000
50TI-30G100S-20C	3900000	4375000	4975000	5250000
40TI-30G100S-30C	4075000	4900000	5025000	5575000
30TI-30G100S-40C	3425000	4075000	4425000	5825000
30TI-50G100S-20C	3775000	4650000	4975000	5750000
20TI-50G100S-30C	3250000	4375000	5150000	5750000
10TI-50G100S-40C	2350000	2800000	4400000	5075000
50TI-30G100S-20F	4425000	4900000	5200000	5225000
40TI-30G100S-20F	4200000	4775000	4875000	5450000
30TI-30G100S-40F	3950000	4600000	4775000	5450000
30TI-50G100S-20F	4200000	4625000	4850000	5050000
20TI-50G100S-30F	4425000	4700000	5000000	5325000
10TI-50G100S-40F	4175000	3950000	4500000	4700000
50TI-30G120S-20C	4475000	4925000	5275000	5650000
40TI-30G120S-30C	4525000	4500000	5075000	5650000
30TI-30G120S-40C	4375000	4650000	5200000	5800000
30TI-50G120S-20C	4650000	5075000	5575000	5800000
20TI-50G120S-30C	4200000	4425000	4900000	5625000
10TI-50G120S-40C	N/A	2150000	4275000	5325000
50TI-30G120S-20F	4390000	4950000	5250000	5875000
40TI-30G120S-30F	4575000	4900000	5325000	5925000
30TI-30G120S-40F	4450000	4400000	4800000	5625000
30TI-50G120S-20F	4550000	4925000	5125000	5675000
20TI-50G120S-30F	4300000	4725000	4825000	4800000
10TI-50G120S-40F	3600000	4250000	4300000	4775000
60TI-20C-20F	4300000	4450000	5025000	5625000
40TI-30C-30F	3625000	4750000	4325000	5000000
20TI-40C-40F	2975000	3275000	3200000	4325000

Table 8
Average Poisson's ratio results for all mixtures

Mixture ID	7 Day	14 Day	28 Day	90 Day
100TI	0.20	0.21	0.23	0.26
80TI-20C	0.22	0.22	0.23	0.21
80TI-20F	0.20	0.20	0.20	0.20
50TI-50G100S	0.19	0.21	0.22	0.21
50TI-50G120S	0.22	0.21	0.19	0.23
50TI-30G100S-20C	0.20	0.21	0.22	0.22
40TI-30G100S-30C	0.19	0.12	0.21	0.23
30TI-30G100S-40C	0.16	0.15	0.20	0.23
30TI-50G100S-20C	0.18	0.21	0.23	0.23
20TI-50G100S-30C	0.23	0.18	0.20	0.24
10TI-50G100S-40C	0.42	0.25	0.20	0.24
50TI-30G100S-20F	0.19	0.20	0.22	0.25
40TI-30G100S-20F	0.19	0.21	0.23	0.23
30TI-30G100S-40F	0.17	0.21	0.24	0.24
30TI-50G100S-20F	0.21	0.21	0.23	0.24
20TI-50G100S-30F	0.22	0.23	0.22	0.23
10TI-50G100S-40F	0.21	0.18	0.21	0.24
50TI-30G120S-20C	0.20	0.23	0.23	0.26
40TI-30G120S-30C	0.19	0.20	0.19	0.23
30TI-30G120S-40C	0.23	0.21	0.23	0.25
30TI-50G120S-20C	0.22	0.24	0.25	0.23
20TI-50G120S-30C	0.18	0.24	0.23	0.25
10TI-50G120S-40C	N/A	0.18	0.14	0.23
50TI-30G120S-20F	0.19	0.21	0.23	0.24
40TI-30G120S-30F	0.21	0.21	0.25	0.21
30TI-30G120S-40F	0.21	0.21	0.23	0.22
30TI-50G120S-20F	0.19	0.25	0.23	0.24
20TI-50G120S-30F	0.22	0.23	0.23	0.21
10TI-50G120S-40F	0.23	0.24	0.22	0.24
60TI-20C-20F	0.20	0.21	0.22	0.23
40TI-30C-30F	0.21	0.25	0.22	0.24
20TI-40C-40F	0.23	0.20	0.20	0.19

Permeability

The RCP results are shown in Figure 13 to Figure 18. The results shown in Figure 13 illustrate typical permeability results for a straight portland cement mixture compared to other binary mixtures. The replacement of portland cement leads to a reduction in permeability as expected.

Figure 14 to Figure 17 show the influence of ternary mixtures on the permeability of the resulting concrete. Note that all ternary mixtures containing combinations of slag and fly ash fell below the very low permeability threshold of 1000 Coulombs, acceptable in the new LADOTD specifications for structural concrete, which call for a permeability value of less than 1500 Coulombs.

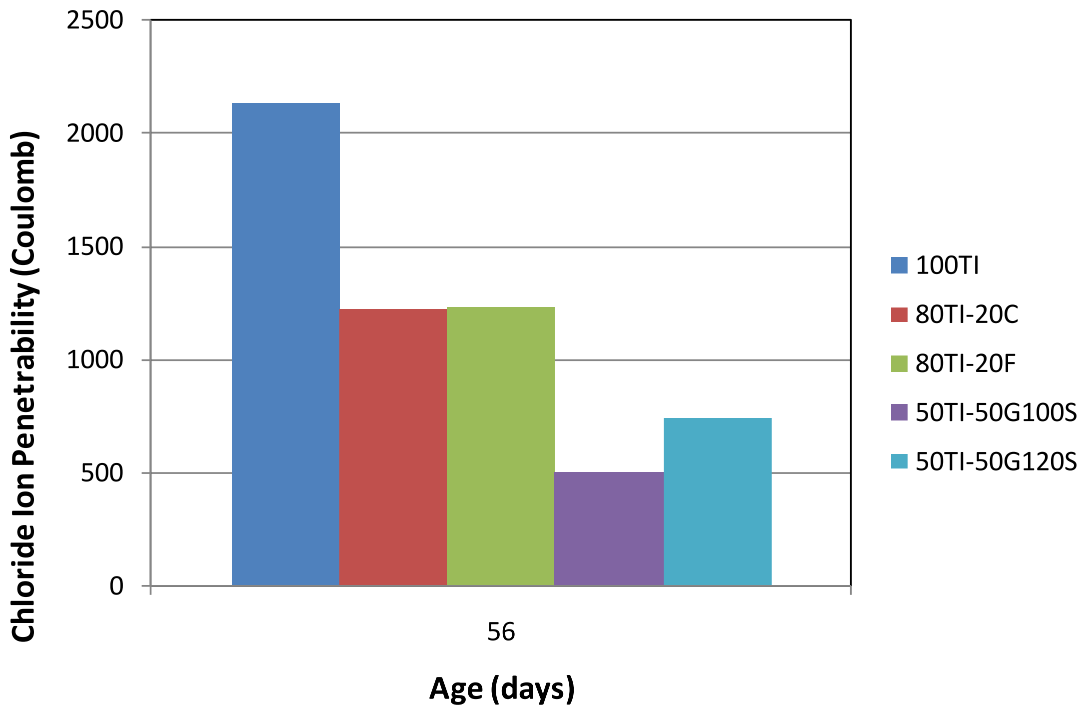

Figure 13
Rapid chloride permeability results for the control mixtures

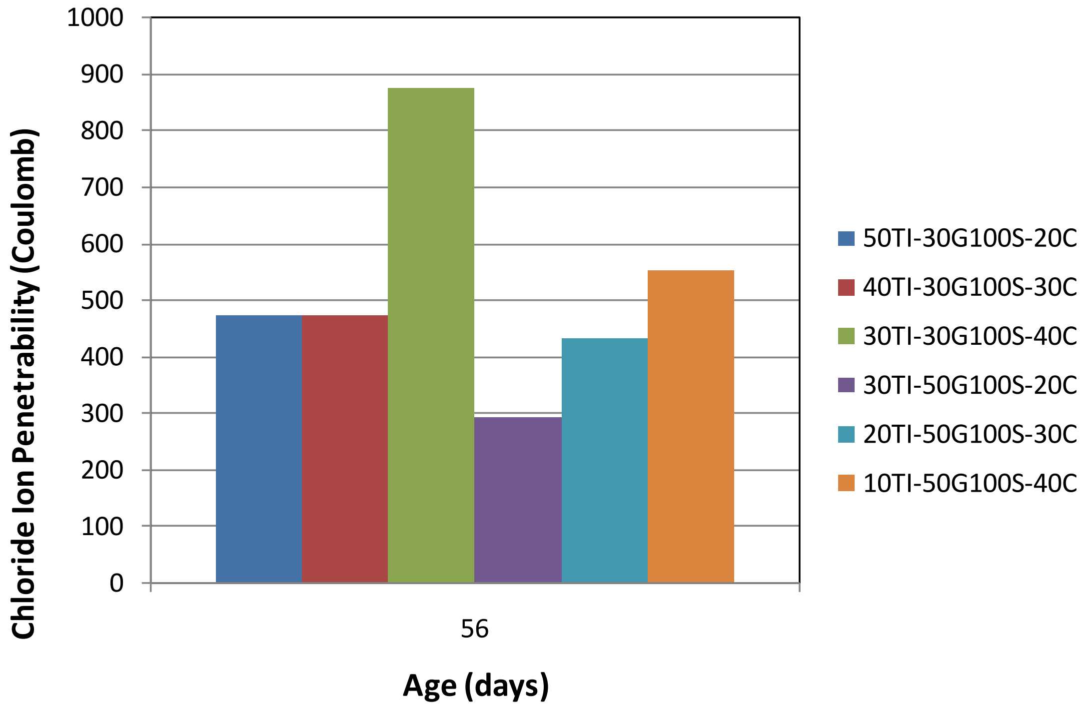

Figure 14
Rapid chloride permeability results for mixtures containing 100 grade slag and class C fly ash

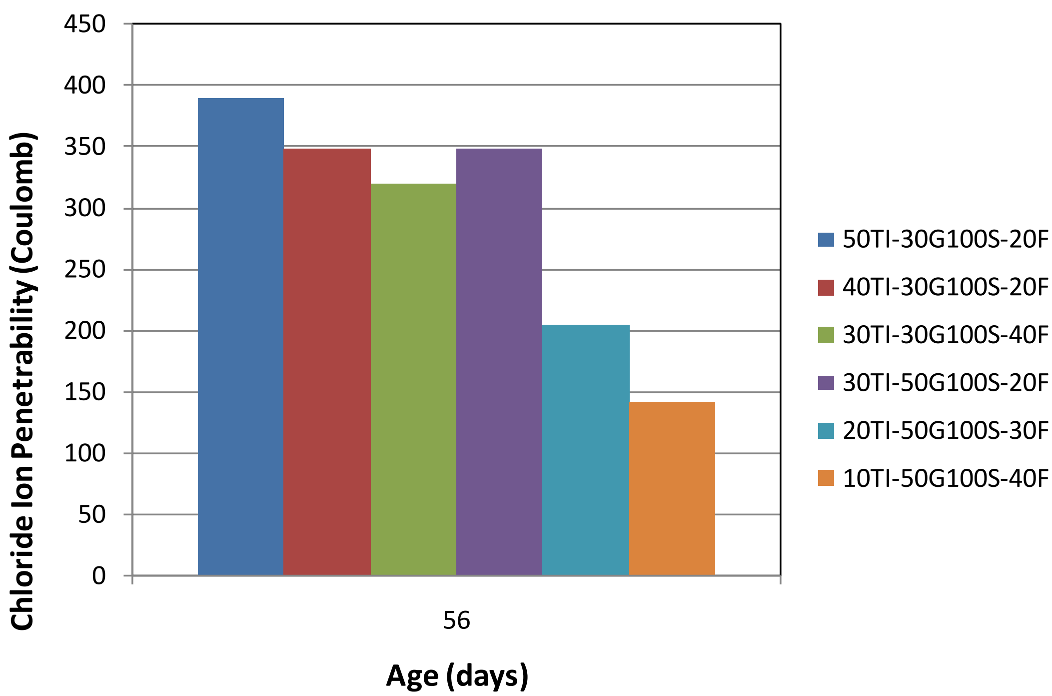

Figure 15
Rapid chloride permeability results for mixtures containing grade 100 slag and class F fly ash

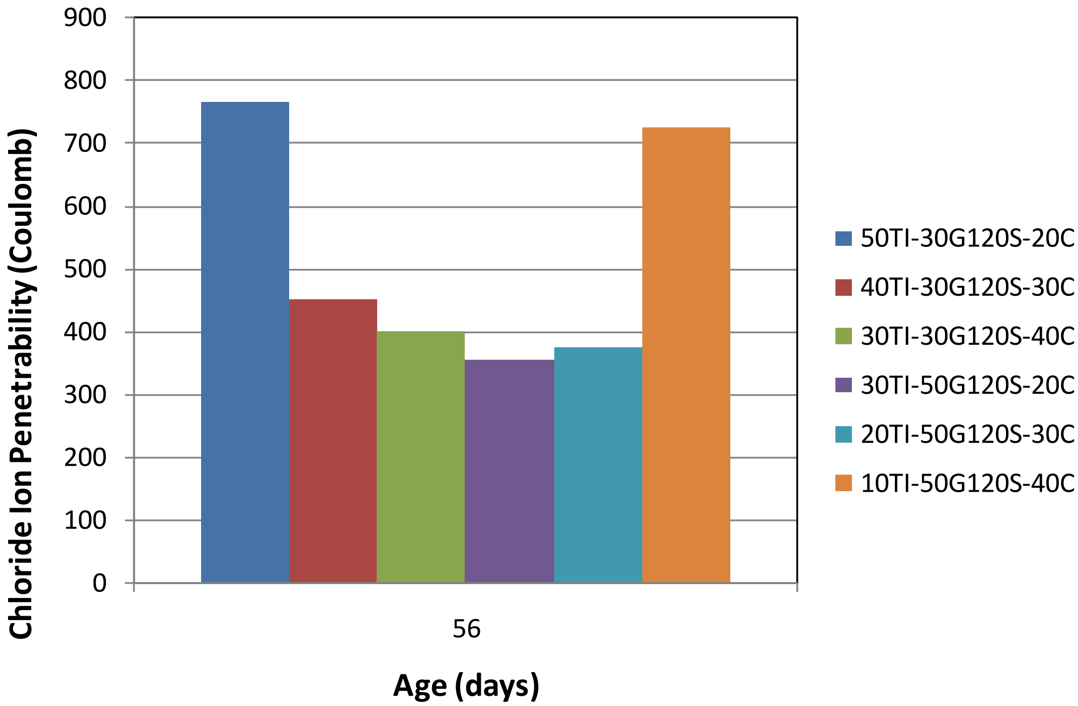

Figure 16
Rapid chloride permeability results for mixtures containing grade 120 slag and class C fly ash

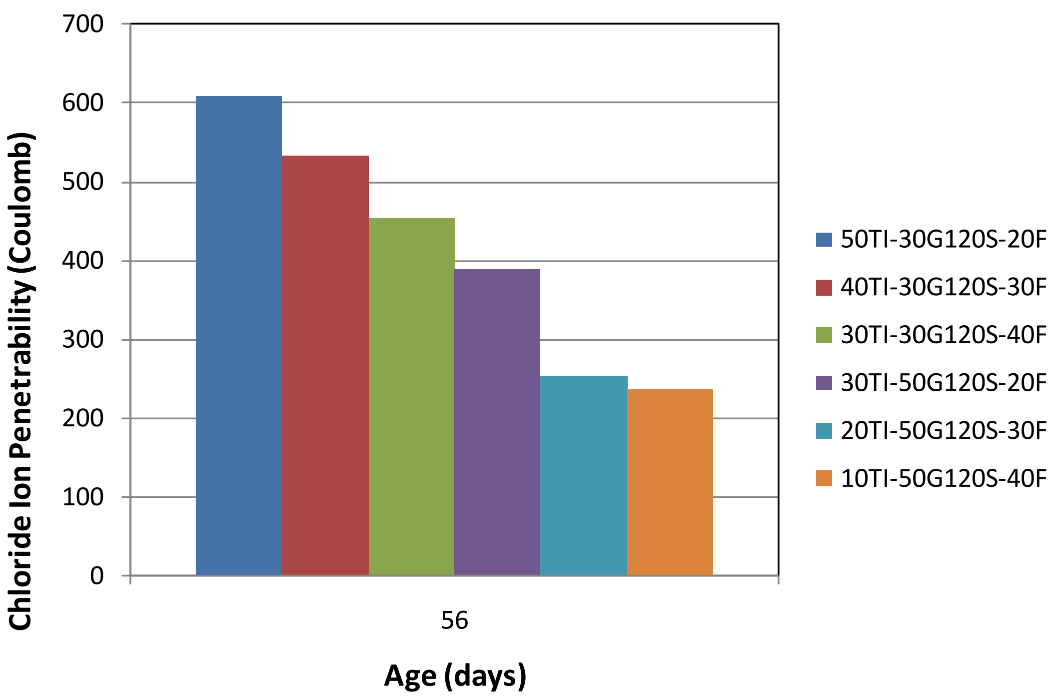

Figure 17
Rapid chloride permeability results for mixtures containing grade 120 slag and class F fly ash

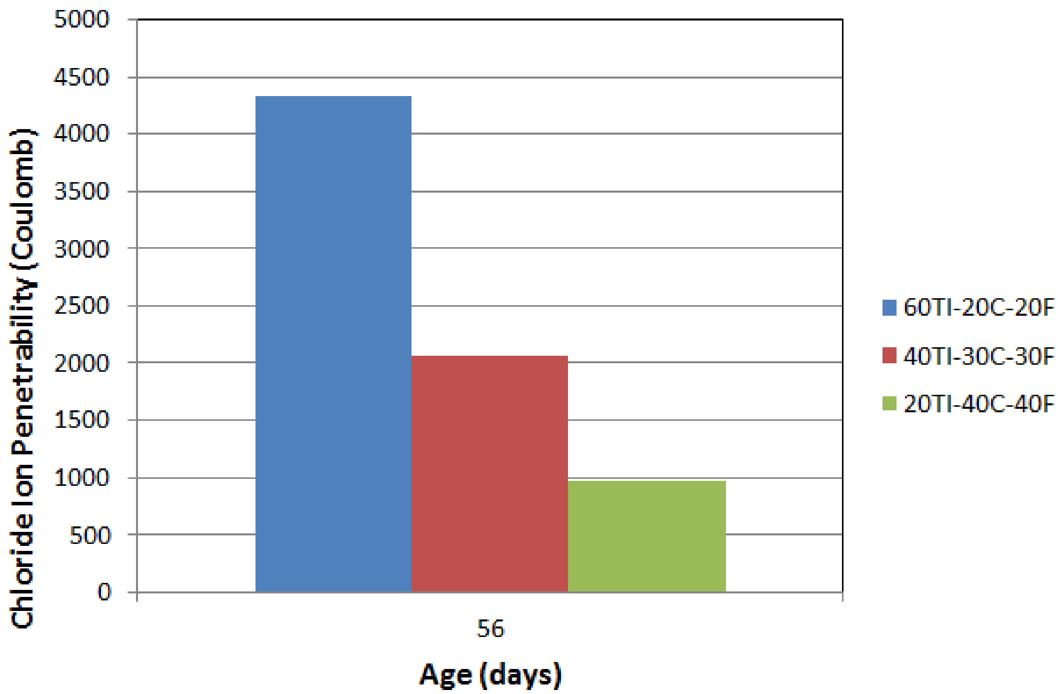

Figure 18
Rapid chloride permeabiltiy results for mixtures containing class C and class F fly ash

It is important to note that use of class F fly ash decreased the permeability of the concrete more so than the use of class C fly ash in combination with slag. This is due to the class F fly ash being more pozzolanic with a greater portion of the ash being in the glass phase.

The results for ternary mixtures containing both class C and class F fly ash are shown in Figure 18. The author expected a greater reduction in permeability for the 40 percent replacement. The high permeability values are most likely due to the pozzolanic action not being fully completed at 56-days of age. The research team has retained several samples for later age testing at one year.

Although the ternary mixtures exceed the proposed new LADOTD permeability specifications (1500 Coulombs at 56 days or 27 kΩ-cm at 28 days), the author strongly cautions against the use of the combinations without first conducting trail batches. While ternary combinations will greatly assist in reduction of permeability of concrete, other factors influence the concrete permeability such as paste content, w/cm, and curing conditions.

It is important to note that the permeability results shown in this report will continue to improve at later ages. It is common knowledge that the permeability can improve up to 365 days after concrete placement in ideal conditions. If the samples tested for this study were to be re-tested at later ages such as one year of age, the permeability values would be significantly better.

Coefficient of Thermal Expansion

The CTE results are shown in Figure 19 to Figure 24. The results are typical for mixtures containing limestone as the coarse aggregate source. The addition of SCMs at high replacement percentages tend to increase the CTE value slightly from 9.7 to about 10 X $10^{-6}/^{o}C$ as noted for three mixtures in Figure 23. These differences may require a change in joint spacing for pavements depending upon the results from the MEPDG analysis conducted during the design phase of the project. The addition of high volumes of class C and class F fly ash tended to reverse the trend leading to a great reduction in CTE. These mixtures would potentially be able to have longer joint spacing for PCC pavements.

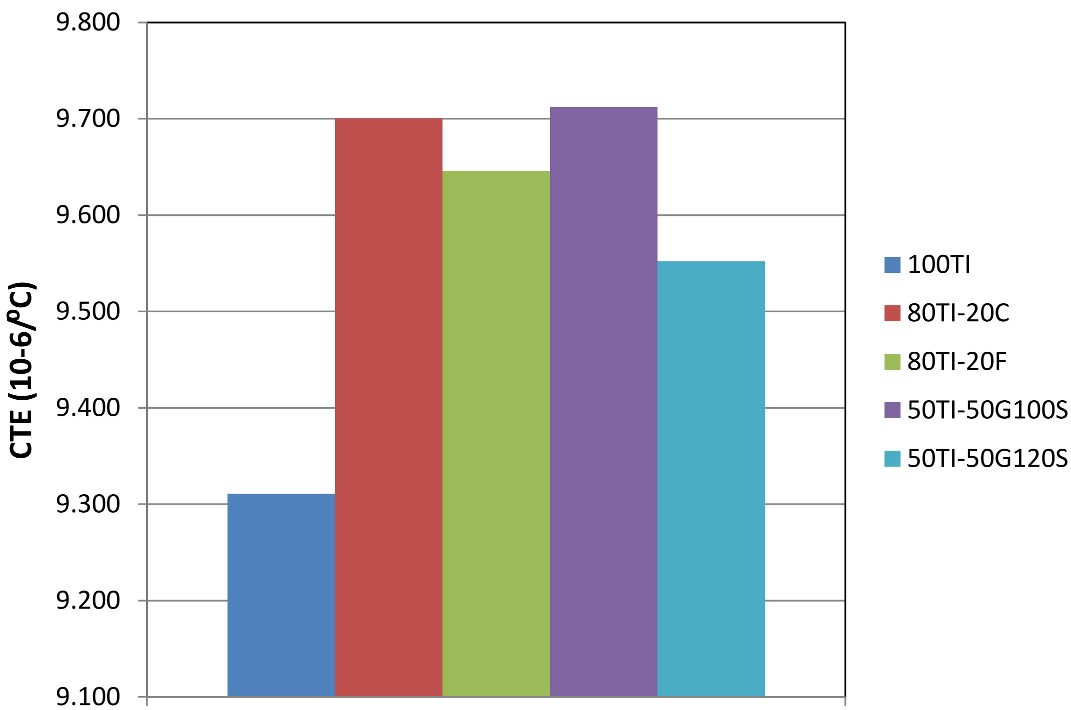

Figure 19
CTE results for the control mixtures

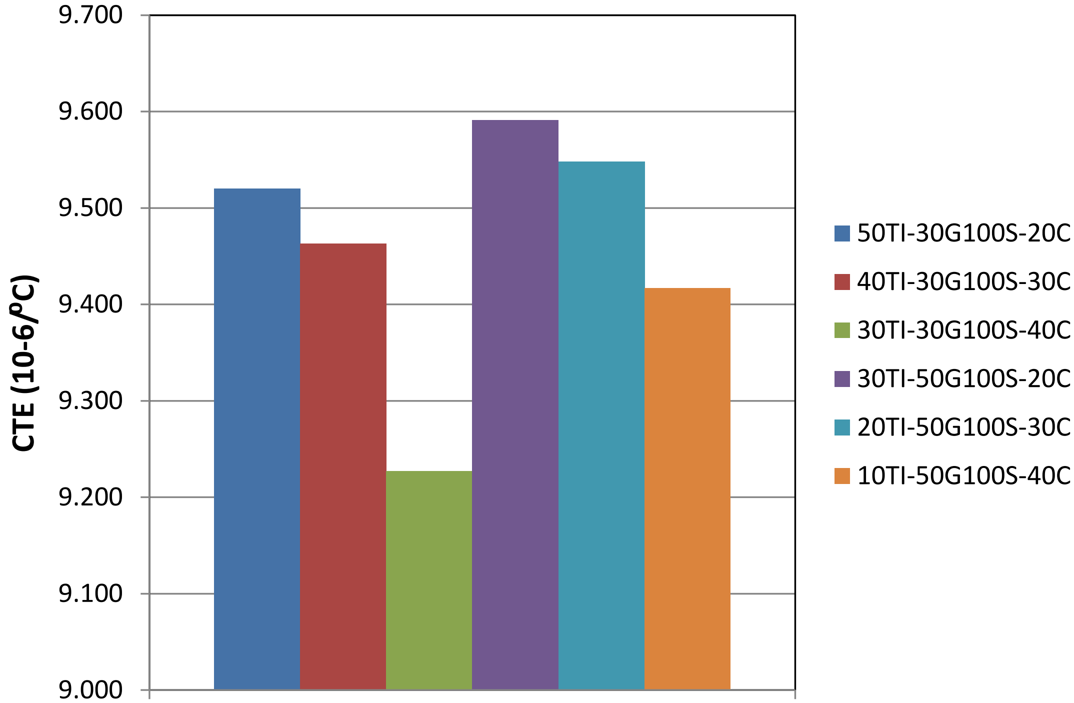

Figure 20
CTE results for mixtures containing grade 100 slag and class C fly ash

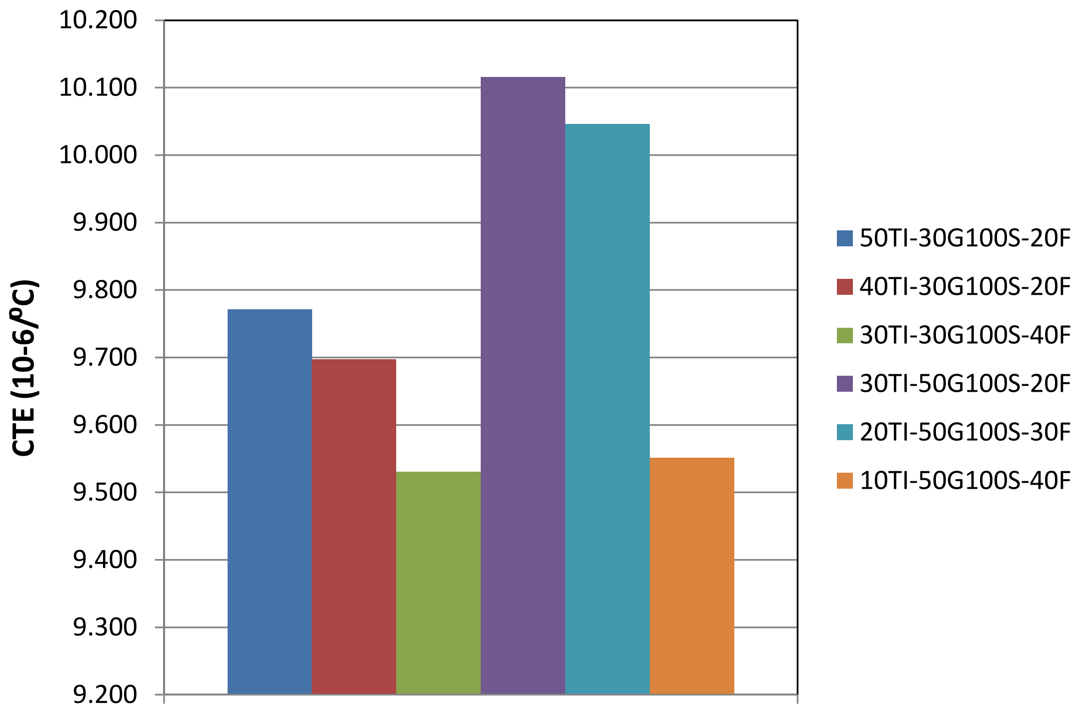

Figure 21
CTE results for mixtures containing grade 100 slag and class F fly ash

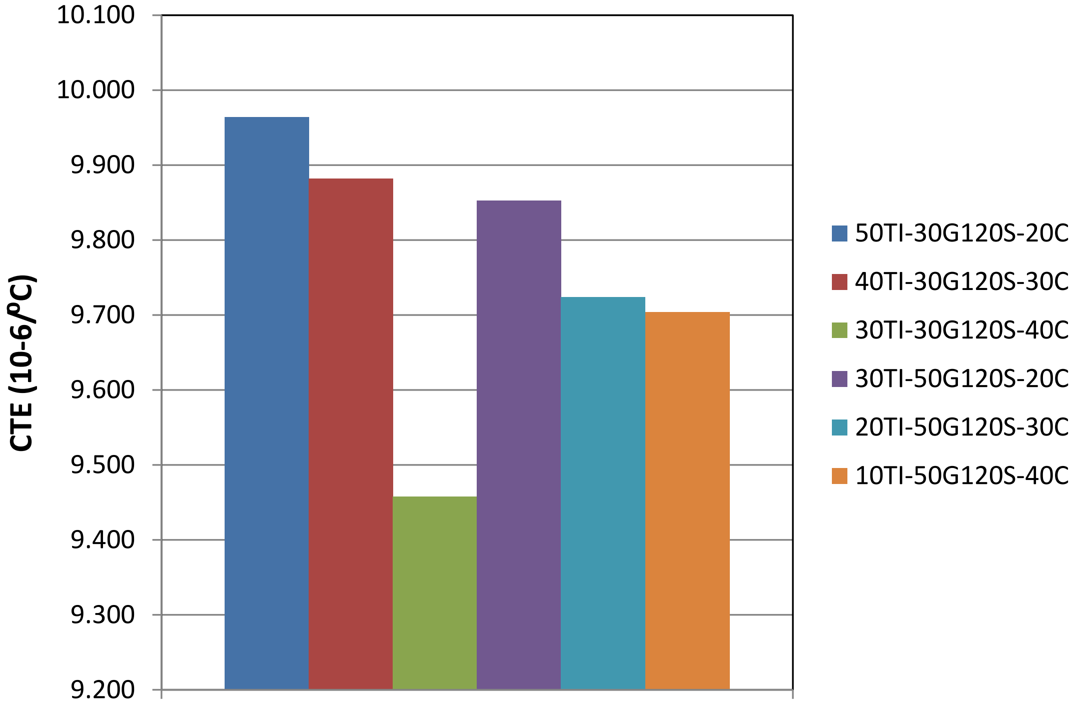

Figure 22
CTE results for mixtures containing grade 120 slag and class C fly ash

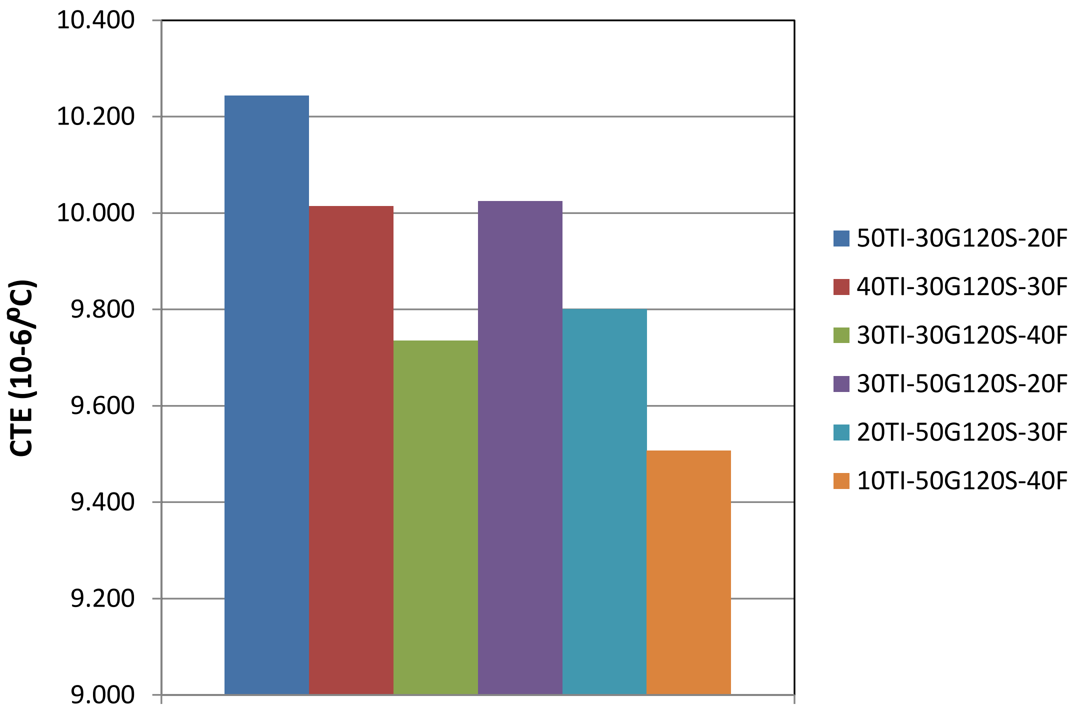

Figure 23
CTE results for mixtures containing grade 120 slag and class F fly ash

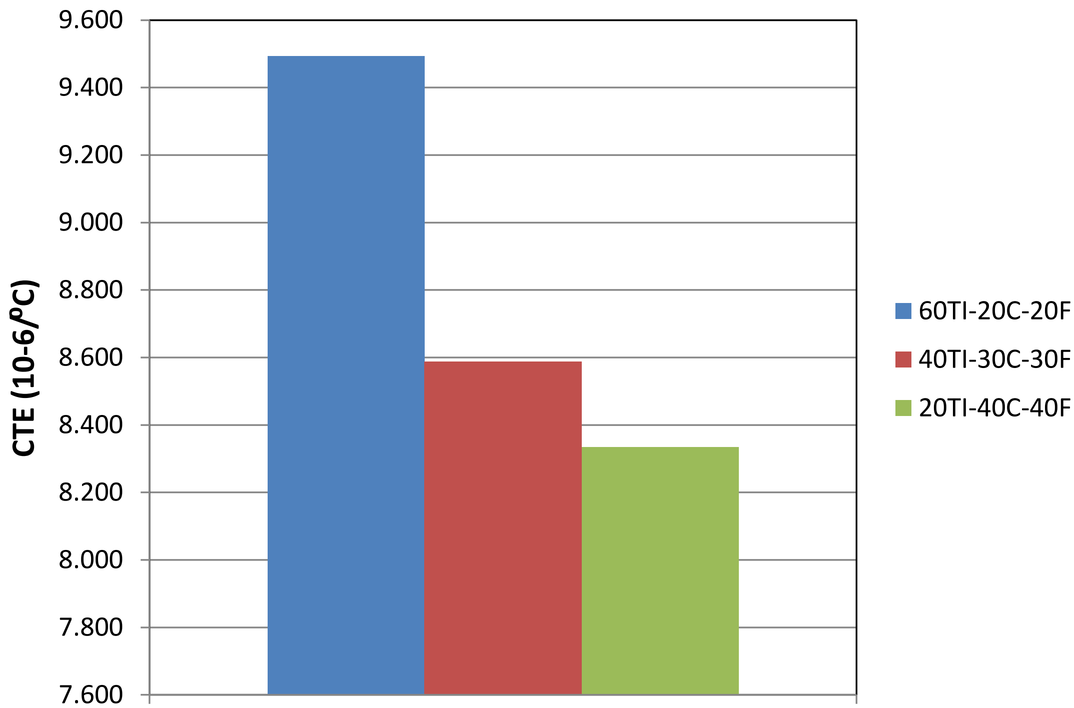

Figure 24
CTE results for mixtures containing class C and class F fly ash

Length Change

The 28-day average length change results for all mixtures are shown in Figure 25 to Figure 30. The control mixtures (Figure 25) showed an average length change of about -0.030 percent when comparing across all mixtures typically used in LADOTD projects. These results are comparable to what others have found in previous research work.

The ternary mixture results (Figure 26 to Figure 30) showed shrinkage results comparable to or less than the control mixtures. The results have far reaching implications in the implementation stage of this research. The results showed that ternary mixtures will be no more prone to shrinkage cracking compared to the control mixtures in ideal curing conditions. The shrinkage results should not be construed to imply that they are more resistant to cracking due to the large number of variables that influence cracking including paste/mortar content and w/cm. Contractor and producer diligence for proper curing procedures is still strongly cautioned for all concrete mixtures being produced and placed on LADOTD projects. Additional applications of curing compound may be required to prevent plastic shrinkage cracking.

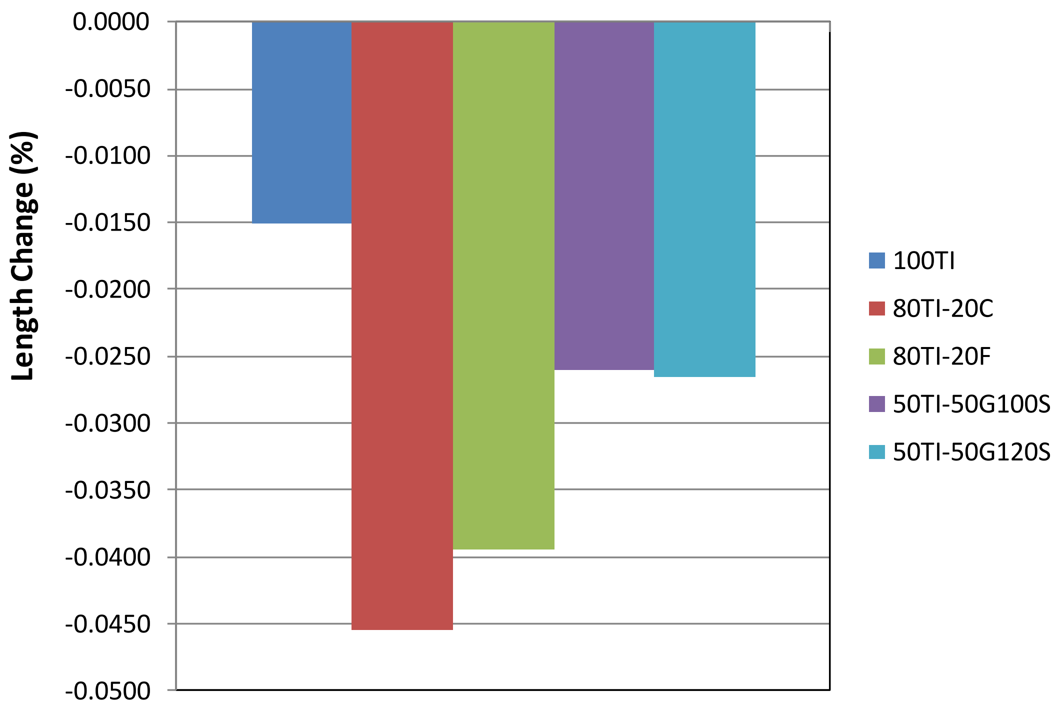

Figure 25
Average length change results for all control mixtures

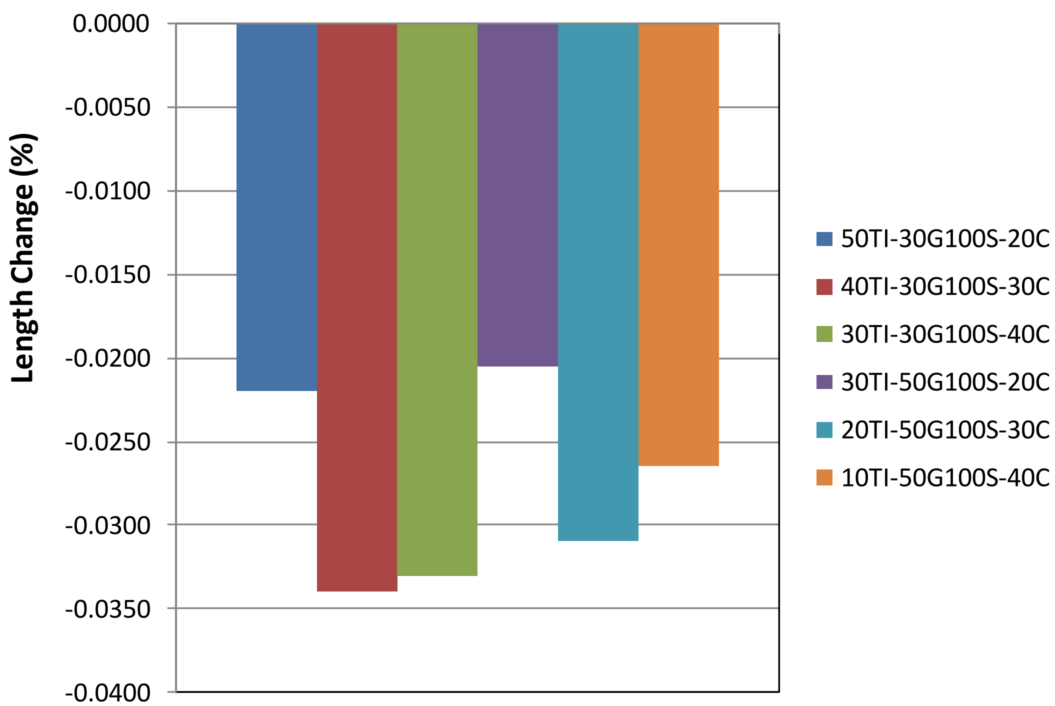

Figure 26
Average length change results for mixtures containing grade 100 slag and class C fly ash

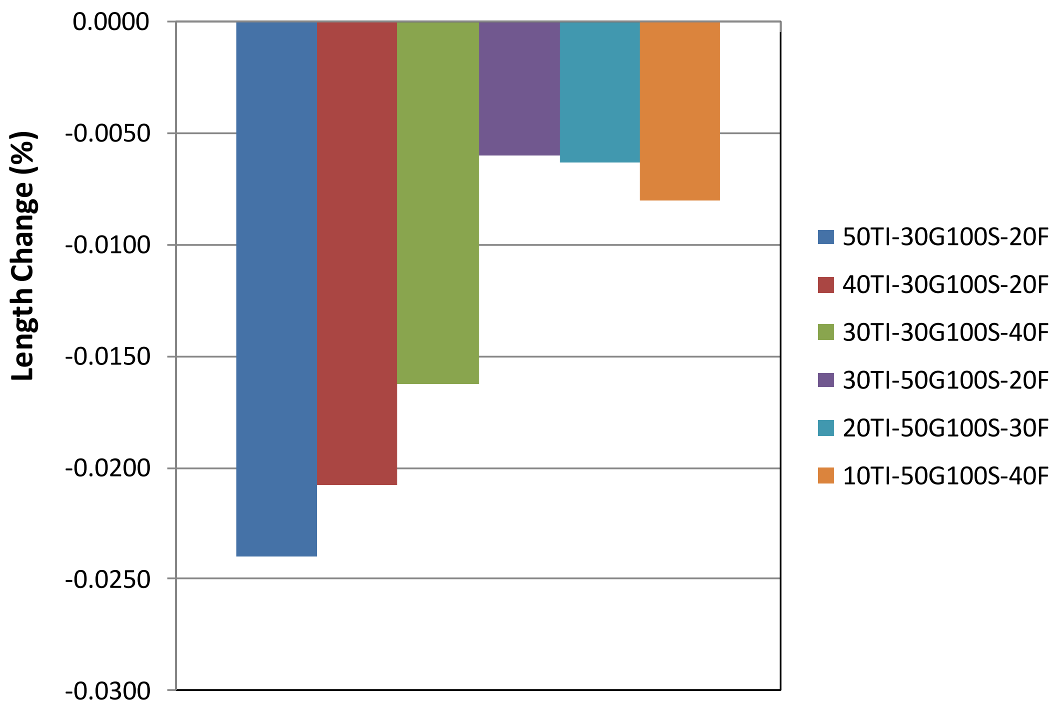

Figure 27
Average length change results for grade 100 slag and class F fly ash

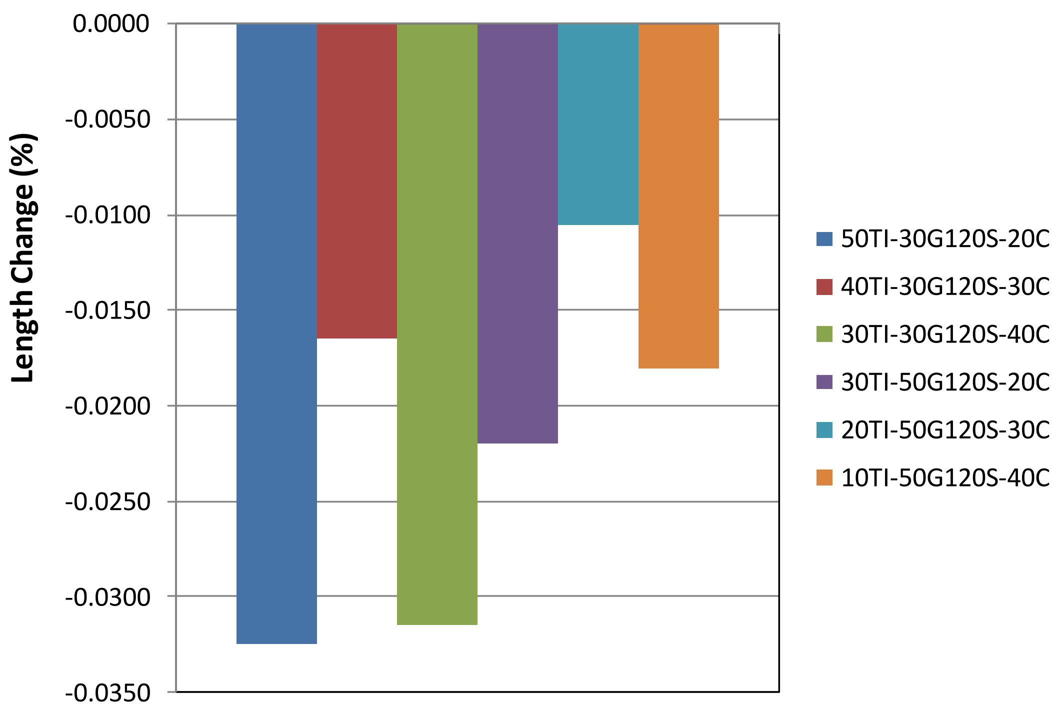

Figure 28
Average length change results for grade 120 slag and class C fly ash

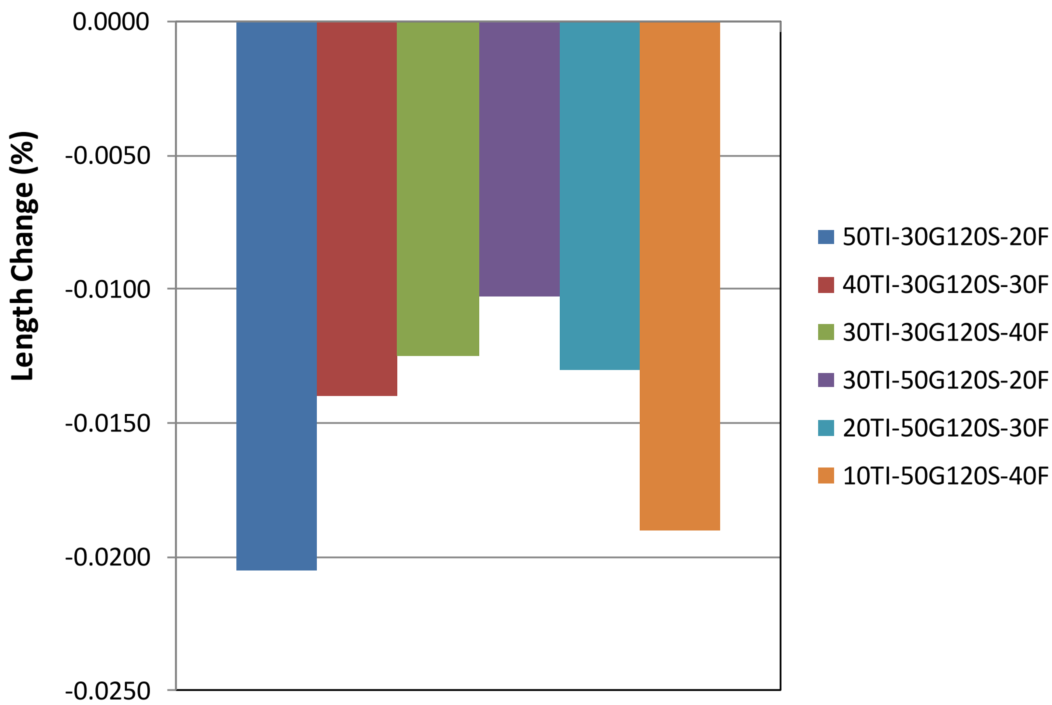

Figure 29
Average length change results for mixtures containing grade 120 slag and class F fly ash

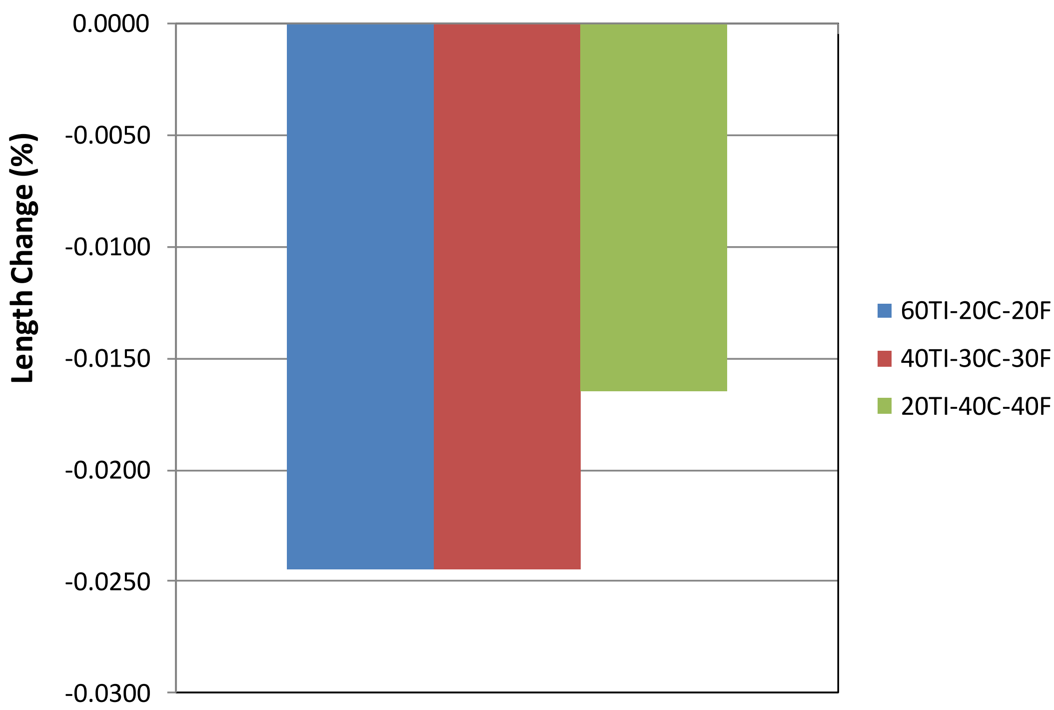

Figure 30
Average length change results for mixtures containing class C and class F fly ash

Freeze-Thaw Durability

The freeze-thaw durability results are shown in Figure 31 to Figure 36. The control mixtures performed as expected with durability factors greater than 75 percent after 300 cycles. The ternary mixtures containing 100 grade slag and class C fly ash (see Figure 32) performed comparable to the control mixtures with the exception of the 50 percent replacement. This mixture performed poorly due to the low entrained air content and has been re-mixed and is being retested at the time of this publication.

Other ternary mixtures have performed adequately with durability factors greater than 60 percent after 300 cycles. Note that some mixtures performed very poorly and have been re-mixed and are currently being retested due to low entrained air content. All of the ternary mixtures with replacements at 90 percent performed much worse than anticipated with many of them not making it through the first round of cycles in the freeze-thaw chamber even though the air contents were adequate to provide freeze-thaw resistance (see Figure 33 and Figure 35).

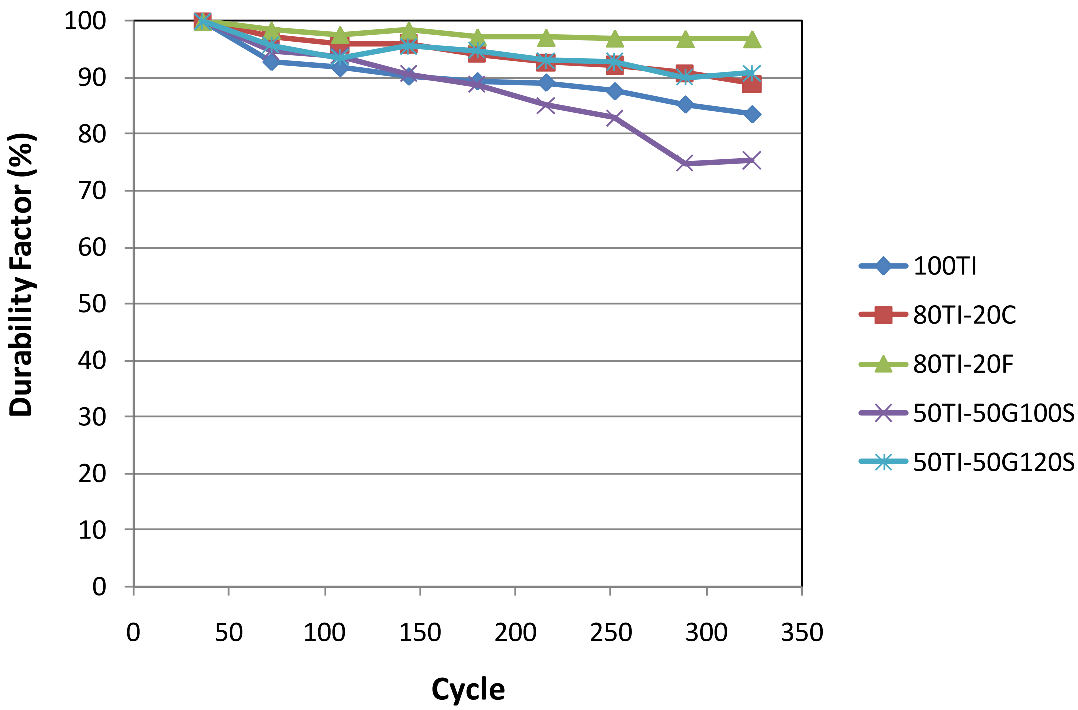

Figure 31
Freeze-thaw durability results for the control mixtures

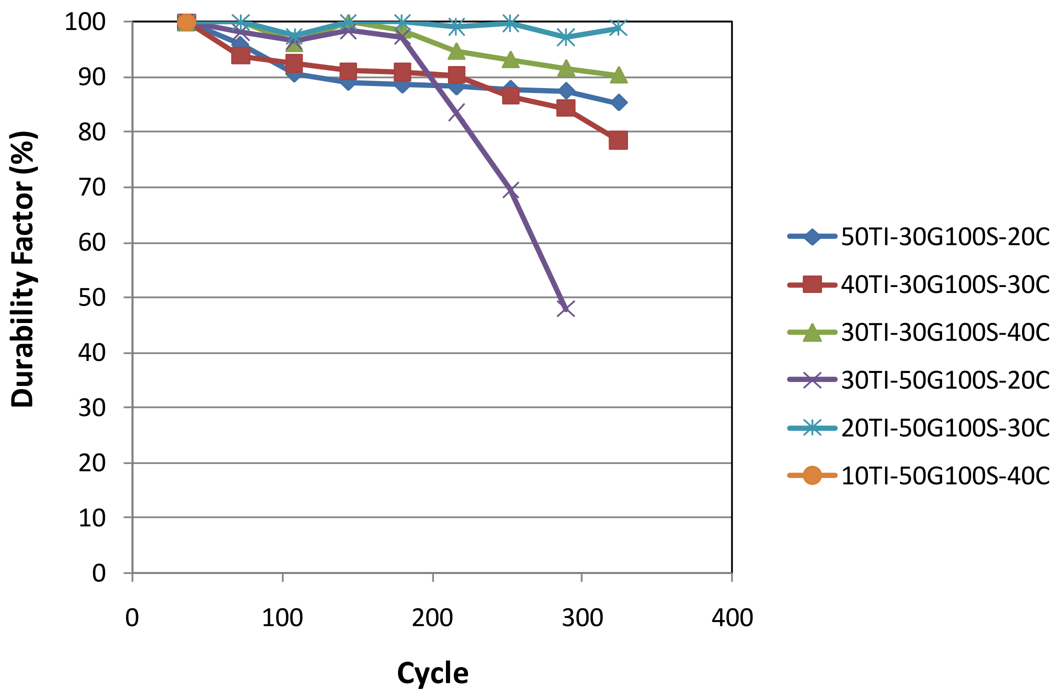

Figure 32
Freeze-thaw durability results for mixtures containing 100 grade slag and class C fly ash

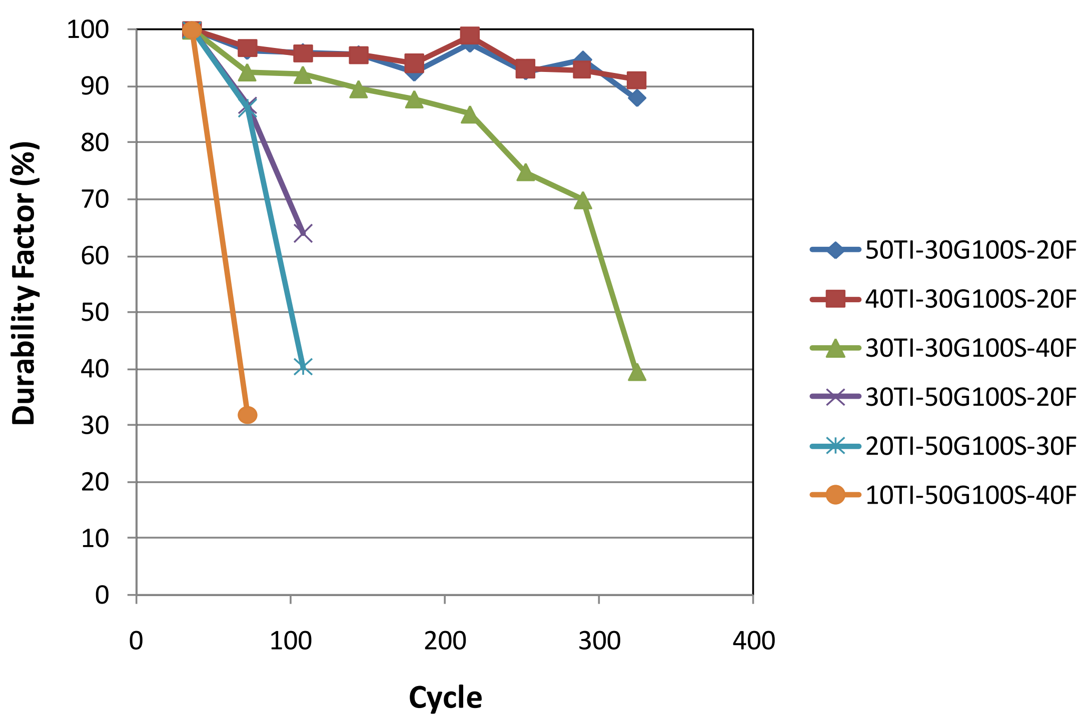

Figure 33
Freeze-thaw durability results for mixtures containing grade 100 slag and class F fly ash

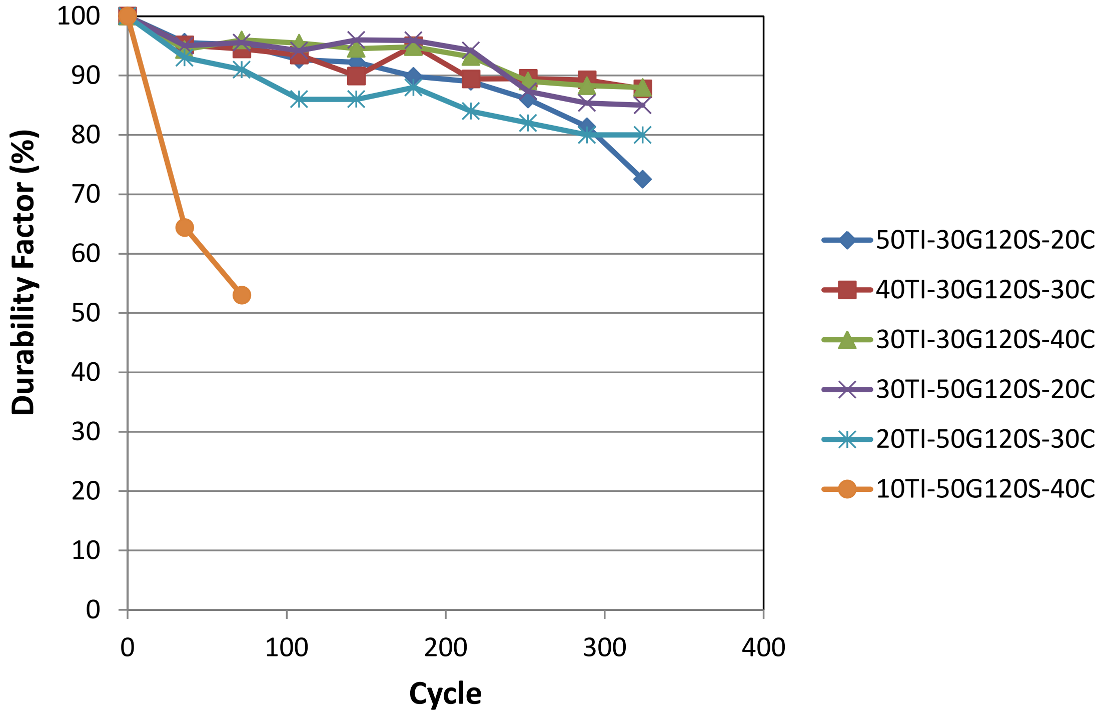

Figure 34
Freeze-thaw durability results for mixtures containing 120 grade slag and class C fly ash

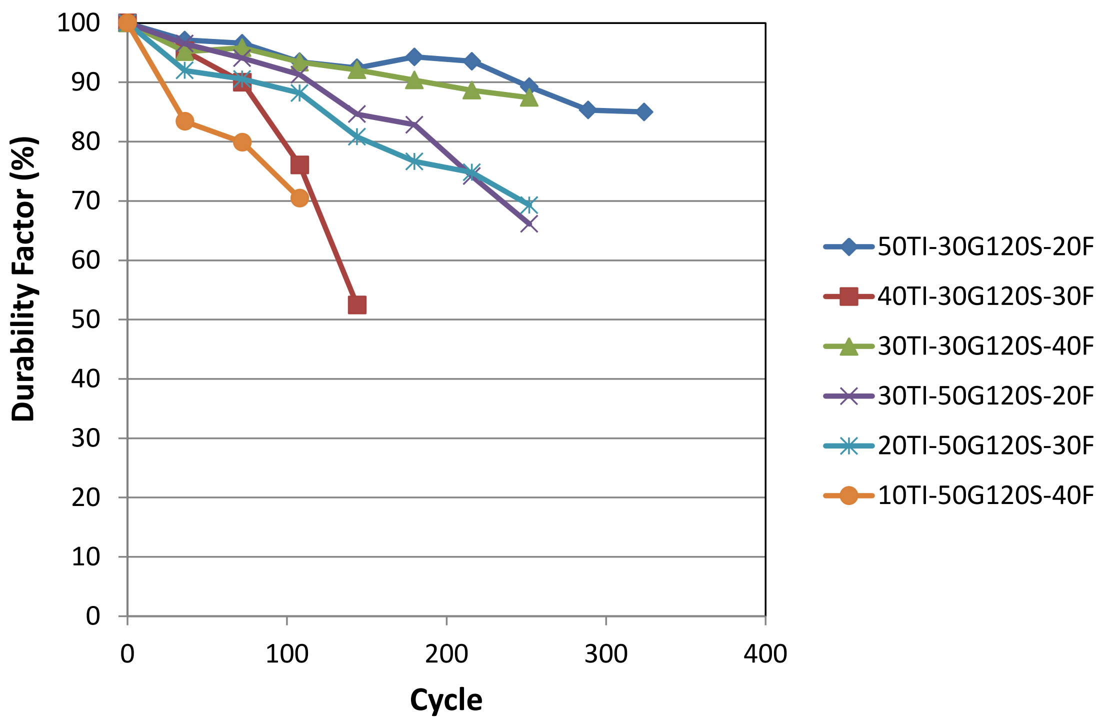

Figure 35
Freeze-thaw durability results for mixtures containing grade 120 slag and class F fly ash

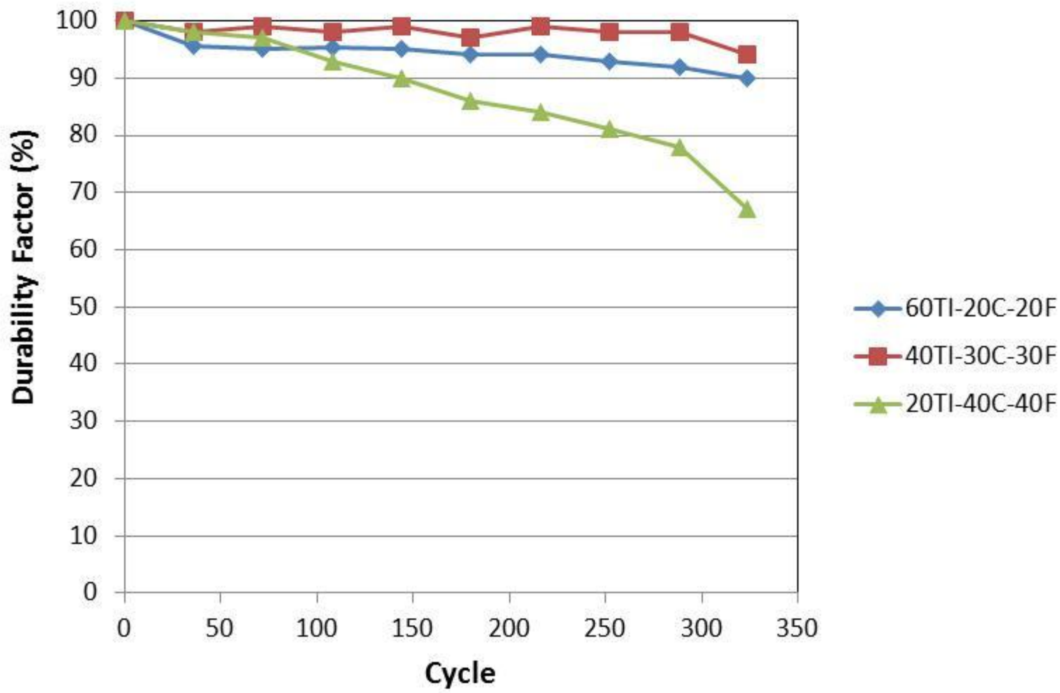

Figure 36
Freeze-thaw durability results for mixtures containing class C and class F fly ash

The low durability factors prompted the retesting of the specimens. Freeze-thaw specimens were prepared and a different curing regime was employed. The specimens were allowed to cure until they attained a compressive strength greater than 3500 psi. Figure 37 shows the original results for the poor performing mixtures compared to those results after remaking and additional curing time. Note the dramatic improvement in the durability factors for all mixtures. With all of the discussion on freeze-thaw, Louisiana conditions provide very little freeze-thaw exposure, and the recommendations for ternary concrete placement temperatures (greater than 50°F) will provide adequate insurance over freeze-thaw damage.

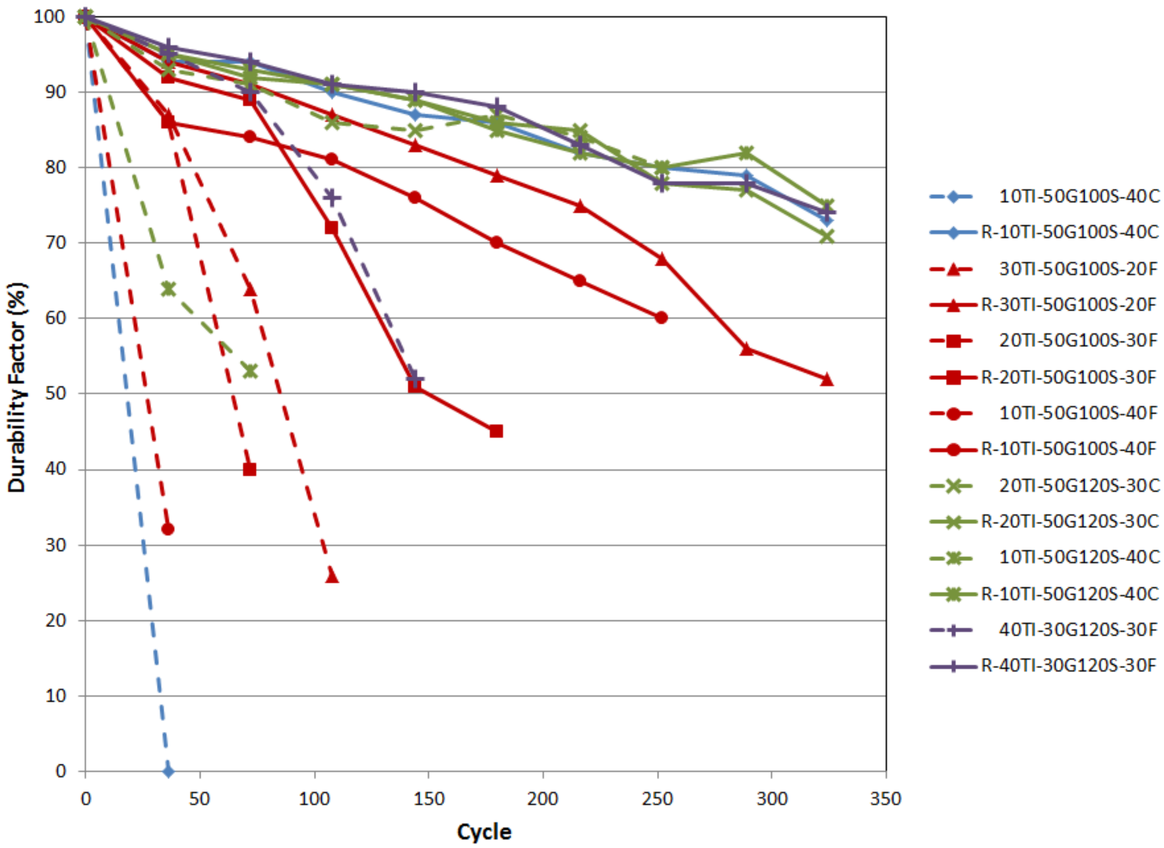

Figure 37
Freeze-thaw durability results comparing the poor performing mixtures and their respective remakes

Cost Benefit Analysis

For the purposes of the cost benefit analysis, a cubic yard of paving concrete was assumed to contain 475 lb. of cementitious material. Using that assumption, Table 9 shows the estimated cost and potential savings, in dollars per mile, for two high SCM replacement mixtures compared to the standard 20 percent fly ash mixture routinely used on LADOTD paving projects. The paving project is assumed to be 10.5 in. thick and 26 ft. in width.

A potential savings of about 17 percent for the mixture containing slag and fly ash exists when a change in specification occurs. A greater savings may be realized when using both class C and class F fly ash of about 28 percent.

Table 9
Estimated cementitious materials cost and potential savings in dollars per mile

Mixture Design	Cementitious Materials Cost ($/mile)	Potential Savings per Mile ($)	Potential Savings per Mile (%)
80TI-20C	$90,566	N/A	N/A
40TI-30G100S-30C	$72,453	$18,113	20.0
30TI-35C-35F	$65,409	$25,157	27.8

During the bid years 2007 and 2008, LADOTD let contracts for about 191 linear miles of PCC pavement. Using the above cementitious costs per mile, Table 10 shows the potential departmental savings if a ternary mixture would have been allowed for these projects.

The cost of this research project was $233,544. Using the savings (benefit) in Table 10, a cost benefit ratio of about 13 and 21 may be realized for the slag – fly ash and class C – class F fly ash ternary mixtures, respectively. Note that these numbers are based on past bid data, and current economic conditions will change these numbers greatly. It is also important to note that these numbers do not take into account the vast quantities of structural concrete that are batched and placed in the state of Louisiana every construction year. Inclusion of the structural concrete data will only improve the cost benefit ratio.

Table 10
Estimated cementitious materials cost and potential savings for bid years 2007 – 2008 (191 miles of PCC pavement)

Mixture Design	Cementitious Materials Cost	Potential Savings ($)	Potential Savings (%)
80TI-20C	$17,298,106	N/A	N/A
40TI-30G100S-30C	$13,838,523	$3,459,583	20.0
30TI-35C-35F	$12,493,119	$4,807,515	27.8

The author notes that the numbers used for the cost benefit analysis are based on averages for Louisiana and the project specific numbers will vary slightly due to transportation hauling and individual market availability of materials.

CO_2 Reduction Analysis

For the purposes of the CO_2 reduction analysis, a cubic yard of paving concrete was assumed to contain 475 lb. of cementitious material. Using that assumption, Table 11 shows the estimated CO_2 load and potential CO_2 savings, in tons, for three high SCM replacement mixtures compared to the standard 20 percent fly ash mixture routinely used on LADOTD paving projects. The pavement cross section is assumed to be 10.5 in. thick and 26 ft. in width.

Table 11
CO_2 Load and potential CO_2 savings for the 2007 - 2008 bid year

Mixture Design	CO_2 Load for the 2007-2008 Bid Years (Tons)	Potential CO_2 Savings (Tons)	Potential CO_2 Savings (%)
80TI-20C	144,531	N/A	N/A
40TI-30G100S-30C	79,456	65,075	43.9
40TI-30G120S-30F	82,321	62,210	41.8
30TI-35C-35F	50,098	94,433	62.5

The potential CO_2 savings range from 42 to 63 percent. These savings are significant. A reduction of 300 tons of CO_2 is equivalent to removing about 8500 vehicles from the road every year. These reductions in carbon dioxide load for the roadway show that the mixtures are sustainable.

These savings will vary significantly depending upon several variables including: total cementitious content of the mixtures, cubic yards of concrete produced, and other factors such as plant efficiency. The author is quick to note that these numbers are conservative due to the fact that they do not include any reduction in CO_2 that would be associated with the large quantities of structural concrete mixed and placed on LADOTD projects every year.

A reduction in CO_2 is great for the portland cement concrete industry, but it is important to note that CO_2 reduction is just a small portion of a much larger complex issue of sustainability. Sustainability also looks at embodied energy, recycled materials usage, material hauling distances, and retro reflectivity among others.

CONCLUSIONS

The results of this study warrant the following conclusions. The fresh concrete results showed adequate workability, air content, and set times for all ternary mixtures with portland cement replacements less than 90 percent.

Compressive strength results showed equal to or greater compressive strengths especially at later ages of 56 and 90 days. The compressive strengths of all mixtures with SCM replacements up to 80 percent met LADOTD specifications of 4000 psi. The ratios of the 7- to 28-day compressive strengths showed that they are more resistant to early age cracking due to the lower modulus at early ages allowing for more creep.

Flexural strengths of the ternary mixtures were generally greater than 650 psi with some reaching 1000 psi. These results show that the mixtures will prove adequate for most concrete paving applications, including interstate applications. The results also indicate that the pavement thickness may be reduced in some instances for certain traffic loading conditions.

The length change, or shrinkage, results showed that the ternary mixtures performed the same or better than the control mixtures. This ensures that the risk of shrinkage cracking of properly mixed, placed, and cured ternary concrete mixtures is no greater than that of currently mixed, placed, and cured concrete mixtures. Additional curing may be required to prevent plastic shrinkage cracking.

The rapid chloride permeability results show that the majority of the ternary mixtures will easily meet the new permeability specifications for all structural class concrete requiring less than 1500 Coulombs at 56 days or 27 kΩ-cm at 28 days of age.

The CTE results showed that the CTE values increased slightly for some combinations of ternary mixtures while decreasing significantly for ternary mixtures containing both class C and class F fly ash. A pavement design analysis will need to be completed to determine proper joint spacing.

The freeze-thaw results showed adequate freeze-thaw durability when the entrained air content was sufficient to prevent frost damage. The results point to an inadequacy in the ASTM standard for high SCM replacements in that the resulting concrete is usually not of sufficient strength to resist freeze-thaw damage at 14 days of age when the test is started. A change may need to be instituted for states where freeze-thaw damage is of concern where the concrete being tested is allowed to cure for a greater numbers of days before the onset of testing.

The cost benefit ratio for implementation of the results may be as high as 21 depending upon the mixture used for construction and the number of cubic yards of concrete constructed in the state on any given year. Implementation of ternary mixtures will result in an estimated 60,000 tons of CO_2 saved for PCC pavements only and the number will be increased when accounting for structural concrete.

All the above results point to a reasonable portland cement replacement level with SCMs of about 70 percent for LADOTD concrete projects. Care should be taken when interpreting these results and the results apply only to the materials used and tested through the course of this study. Producers and contractors wanting to implement these results are strongly encouraged to produce trial batches with their locally available materials to ensure the mixture's ability to meet and exceed the standards and specifications.

RECOMMENDATIONS

The author recommends full implementation of the results of this study and suggests a maximum portland cement replacement of 70 percent. Ternary combinations containing class C and class F fly ash should be allowed, but be incorporated in equal amounts. Slag and fly ash combinations may be used with the exception being that the fly ash content cannot be greater than the slag content. Lastly, the cold weather limitation should be set such that risk of cracking and delayed set times are minimized. To this end, the author suggests a cold weather limitation of about 50°F, the temperature at which ternary concrete operations should cease.

ACRONYMS, ABBREVIATIONS & SYMBOLS

AASHTO	American Association of State Highway and Transportation Officials
CTE	coefficient of thermal expansion
DOTs	Departments of Transportation
FHWA	Federal Highway Administration
ft.	feet
GGBFS	ground granulated blast furnace slag
in.	inch(es)
LADOTD	Louisiana Department of Transportation and Development
LTRC	Louisiana Transportation Research Center
MEPDG	Mechanistic Empirical Pavement Design Guide
PCA	Portland Cement Association
PCC	portland cement concrete
pcf	pounds per cubic foot
psi	pounds per square inch
SCMs	supplementary cementitious materials
w/cm	water to cementitious materials ratio
XRF	X-ray fluorescence

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APPENDIX

LTRC Lab. No.	C-3401	C-3402	C-3407	C-3411	C-3430
Mixture ID	100TI	80TI-20C	80TI-20F	50TI-50G100S	50TI-50G120S
Date Made	9/3/2009	9/10/2009	9/24/2009	10/1/2009	11/9/2009
Type I Portland Cement (%)	100	80	80	50	50
Grade 100 Slag (%)				50	
Grade 120 Slag (%)					50
Class C Fly Ash (%)		20			
Class F Fly Ash (%)			20		
Water Reducer (ZYLA 620 oz/100ct)	5.00	5.00	4.00	3.00	3.00
Air Entrainment (Daravair 1000 oz/100ct)	0.50	0.50	0.50	0.50	0.50
Fresh Concrete Tests					
Slump (inches)	2.25	5.00	5.00	2.50	4.00
Air Content (%)	4.50	6.00	5.80	4.40	5.10
Unit Weight (lbs/ft³)	147.4	144.0	144.0	146.6	144.2
Initial Set Time (hrs:mins)	4:47	7:14	5:50	5:38	5:34
Final Set Time (hrs:mins)	6:13	8:45	7:23	7:45	7:51
ASTM C 39, Compressive Strength (psi), 4x8 cyls.					
Age at testing (7 days)					
Cylinder #1	5424	4335	3792	4429	4866
Cylinder #2	5443	3793	3940	4146	4626
Cylinder #3	5470	4368	3988	4687	5072
Average	**5446**	**4165**	**3907**	**4421**	**4855**
Standard Deviation	**23.12**	**322.87**	**102.16**	**270.60**	**223.22**
Coefficient of Variance	***0.42***	***7.75***	***2.62***	***6.12***	***4.60***
Age at testing (14 days)					
Cylinder #4	5905	4197	4340	6256	6297
Cylinder #5	5605	4636	4198	6102	5952
Cylinder #6	5892	4144	4458	6070	6108
Average	**5801**	**4326**	**4332**	**6143**	**6119**
Standard Deviation	**169.58**	**270.06**	**130.18**	**99.45**	**172.76**
Coefficient of Variance	***2.92***	***6.24***	***3.01***	***1.62***	***2.82***
Age at testing (28 days)					
Cylinder #7	6156	5139	4714	7024	6796
Cylinder #8	6044	4574	5054	6636	6957
Cylinder #9	5380	4857	4758	6696	7116
Average	**5860**	**4857**	**4842**	**6785**	**6956**
Standard Deviation	**419.45**	**282.50**	**184.91**	**208.86**	**160.00**
Coefficient of Variance	***7.16***	***5.82***	***3.82***	***3.08***	***2.30***
Age at testing (56 days)					
Cylinder #10	6451	5735	5217	6994	7798
Cylinder #11	6347	5750	5405	6591	7742
Cylinder #12	6451	5412	5467	7042	7858
Average	**6416**	**5632**	**5363**	**6876**	**7799**
Standard Deviation	**60.04**	**190.96**	**130.18**	**247.69**	**58.01**
Coefficient of Variance	***0.94***	***3.39***	***2.43***	***3.60***	***0.74***
Age at testing (90 days)					
Cylinder #13	6550	5157	5591	7572	7626
Cylinder #14	6829	5881	5501	7439	7249
Cylinder #15	6725	5522	5658	7363	8092
Average	**6701**	**5520**	**5583**	**7458**	**7656**
Standard Deviation	**141.00**	**362.00**	**78.78**	**105.79**	**422.28**
Coefficient of Variance	***2.10***	***6.56***	***1.41***	***1.42***	***5.52***

LTRC Lab. No.	C-3401	C-3402	C-3407	C-3411	C-3430
Mixture ID	100TI	80TI-20C	80TI-20F	50TI-50G100S	50TI-50G120S
ASTM C 469, Static Modulus of Elasticity and Poisson's Ratio of Concrete in Compression (4x8 cylinders)					
Age at testing (7 days)					
Modulus					
Cylinder #2	4,950,000	4,100,000	4,450,000	4,350,000	4,500,000
Cylinder #3	4,840,000	4,300,000	4,250,000	4,450,000	4,650,000
Average	**4,895,000**	**4,200,000**	**4,350,000**	**4,400,000**	**4,575,000**
Standard Deviation	**77781.75**	**141421.36**	**141421.36**	**70710.68**	**106066.02**
Coefficient of Variance	***1.59***	***3.37***	***3.25***	***1.61***	***2.32***
Poisson's Ratio					
Cylinder #2	0.19	0.22	0.20	0.20	0.22
Cylinder #3	0.20	0.22	0.20	0.17	0.21
Average	**0.20**	**0.22**	**0.20**	**0.19**	**0.22**
Standard Deviation	**0.01**	**0.00**	**0.00**	**0.02**	**0.01**
Coefficient of Variance	***3.63***	***0.00***	***0.00***	***11.47***	***3.29***
Age at testing (14 days)					
Modulus					
Cylinder #5	5,100,000	3,700,000	4,450,000	5,150,000	4,450,000
Cylinder #6	4,900,000	4,650,000	4,350,000	5,050,000	4,800,000
Average	**5,000,000**	**4,175,000**	**4,400,000**	**5,100,000**	**4,625,000**
Standard Deviation	**141421.36**	**671751.44**	**70710.68**	**70710.68**	**247487.37**
Coefficient of Variance	***2.83***	***16.09***	***1.61***	***1.39***	***5.35***
Poisson's Ratio					
Cylinder #5	0.21	0.22	0.23	0.21	0.19
Cylinder #6	0.20	0.22	0.16	0.21	0.23
Average	**0.21**	**0.22**	**0.20**	**0.21**	**0.21**
Standard Deviation	**0.01**	**0.00**	**0.05**	**0.00**	**0.03**
Coefficient of Variance	***3.45***	***0.00***	***25.38***	***0.00***	***13.47***
Age at testing (28 days)					
Modulus					
Cylinder #8	5,250,000	4,500,000	5,250,000	5,450,000	5,000,000
Cylinder #9	5,350,000	4,550,000	4,500,000	5,000,000	5,050,000
Average	**5,300,000**	**4,525,000**	**4,875,000**	**5,225,000**	**5,025,000**
Standard Deviation	**70710.68**	**35355.34**	**530330.09**	**318198.05**	**35355.34**
Coefficient of Variance	***1.33***	***0.78***	***10.88***	***6.09***	***0.70***
Poisson's Ratio					
Cylinder #8	0.22	0.22	0.21	0.23	0.19
Cylinder #9	0.23	0.24	0.18	0.21	0.19
Average	**0.23**	**0.23**	**0.20**	**0.22**	**0.19**
Standard Deviation	**0.01**	**0.01**	**0.02**	**0.01**	**0.00**
Coefficient of Variance	***3.14***	***6.15***	***10.88***	***6.43***	***0.00***
Age at testing (90 days)					
Modulus					
Cylinder #14	5,750,000	5,400,000	5,000,000	5,400,000	5,700,000
Cylinder #15	5,450,000	5,050,000	5,050,000	5,500,000	5,950,000
Average	**5,600,000**	**5,225,000**	**5,025,000**	**5,450,000**	**5,825,000**
Standard Deviation	**212132.03**	**247487.37**	**35355.34**	**70710.68**	**176776.70**
Coefficient of Variance	***3.79***	***4.74***	***0.70***	***1.30***	***3.03***
Poisson's Ratio					
Cylinder #14	0.26	0.18	0.19	0.20	0.21
Cylinder #15	0.26	0.24	0.20	0.21	0.25
Average	**0.26**	**0.21**	**0.20**	**0.21**	**0.23**
Standard Deviation	**0.00**	**0.04**	**0.01**	**0.01**	**0.03**
Coefficient of Variance	***0.00***	***20.20***	***3.63***	***3.45***	***12.30***

LTRC Lab. No.	C-3401	C-3402	C-3407	C-3411	C-3430
Mixture ID	100TI	80TI-20C	80TI-20F	50TI-50G100S	50TI-50G120S
ASTM C 78, Flexure Strength (psi), 6x6x20 beams					
Age at testing (7 days)					
Beam #1	774	694	596	714	837
Beam #2	715	589	717	797	791
Average	**745**	**642**	**657**	**756**	**814**
Standard Deviation	**41.72**	**74.25**	**85.56**	**58.69**	**32.53**
Coefficient of Variance	***5.60***	***11.57***	***13.03***	***7.77***	***4.00***
Age at testing (14 days)					
Beam #3	799	679	751	947	985
Beam #4	797	636	709	849	1227
Average	**798**	**658**	**730**	**898**	**1106**
Standard Deviation	**1.41**	**30.41**	**29.70**	**69.30**	**171.12**
Coefficient of Variance	***0.18***	***4.62***	***4.07***	***7.72***	***15.47***
Age at testing (28 days)					
Beam #5	928	703	654	1072	1159
Beam #6	897	724	697	963	1147
Average	**913**	**714**	**676**	**1018**	**1153**
Standard Deviation	**21.92**	**14.85**	**30.41**	**77.07**	**8.49**
Coefficient of Variance	***2.40***	***2.08***	***4.50***	***7.57***	***0.74***
Age at testing (90 days)					
Beam #7	812	693	667	1036	1216
Beam #8	824	750	712	1081	1171
Average	**818**	**722**	**690**	**1059**	**1194**
Standard Deviation	**8.49**	**40.31**	**31.82**	**31.82**	**31.82**
Coefficient of Variance	***1.04***	***5.59***	***4.61***	***3.01***	***2.67***
ASTM C 157, Length Change of Hardened Concrete (air storage method)					
Percent Length Change 28 days air					
Beam #1	-0.0140	-0.0450	-0.0380	-0.0260	-0.0270
Beam #2	-0.0160	-0.0460	-0.0410	-0.0260	-0.0260
Average	**-0.0150**	**-0.0455**	**-0.0395**	**-0.0260**	**-0.0265**
Standard Deviation	**0.0014**	**0.0007**	**0.0021**	**0.0000**	**0.0007**
Coefficient of Variance	***-9.43***	***-1.55***	***-5.37***	***0.00***	***-2.67***
ASTM C 666, Freeze-Thaw Durability, 3x4x16 beams					
Age at testing (14 days)					
Beam #1	76.7	88.5	95.9	75.2	87.0
Beam #2	81.1	92.4	94.4	73.7	89.6
Beam #3	90.1	85.6	99.6	76.7	94.1
Average	**82.6**	**88.8**	**96.6**	**75.2**	**90.2**
Standard Deviation	**6.83**	**3.41**	**2.68**	**1.50**	**3.59**
Coefficient of Variance	***8.27***	***3.84***	***2.77***	***1.99***	***3.98***
ASTM C 1202, Rapid Chloride Permeability					
Coulombs at 56 days					
Cylinder #16 (Top)	2628	1028	1347	651	892
Cylinder #16 (Middle)	1691	1246	1106	457	710
Cylinder #17 (Top)	2203	1318	1006	462	714
Cylinder #17 (Middle)	2001	1311	1464	448	631
Average	**2131**	**1226**	**1231**	**505**	**737**
Chloride Ion Penetrability	**Moderate**	**Low**	**Low**	**Very Low**	**Very Low**
Standard Deviation	**392.72**	**135.76**	**211.34**	**97.84**	**110.33**
Coefficient of Variance	***18.43***	***11.08***	***17.17***	***19.39***	***14.98***

LTRC Lab. No.	C-3413	C-3423	C-3445	C-3451	C-3456	C-3474
Mixture ID	50TI-30G100S-20C	40TI-30G100S-30C	30TI-30G100S-40C	30TI-50G100S-20C	20TI-50G100S-30C	10TI-50G100S-40C
Date Made	10/8/2009	10/14/2009	1/27/2010	2/4/2010	2/11/2010	3/16/2010
Type I Portland Cement (%)	50	40	30	30	20	10
Grade 100 Slag (%)	30	30	30	50	50	50
Grade 120 Slag (%)						
Class C Fly Ash (%)	20	30	40	20	30	40
Class F Fly Ash (%)						
Water Reducer (ZYLA 620 oz/100ct)	3.00	2.50	1.20	1.20	1.00	1.00
Air Entrainment (Daravair 1000 oz/100ct)	0.50	0.50	0.55	0.55	0.50	0.50
Fresh Concrete Tests						
Slump (inches)	5.00	3.25	6.75	4.25	3.00	3.50
Air Content (%)	5.2	4.7	4.3	3.5	3.9	2.7
Unit Weight (lbs/ft³)	143.4	144.4	147.0	146.4	145.6	147.0
Initial Set Time (hrs:mins)	5:55	6:04	10:21	7:57	9:27	10:53
Final Set Time (hrs:mins)	8:13	8:18	13:13	10:57	13:04	19:33
ASTM C 39, Compressive Strength (psi), 4x8 cyls.						
Age at testing (7 days)						
Cylinder #1	2502	3011	1821	2603	1475	501
Cylinder #2	2616	3138	1928	2677	1339	494
Cylinder #3	2561	2922	1714	2649	1357	475
Average	**2560**	**3024**	**1821**	**2643**	**1390**	**490**
Standard Deviation	**57.01**	**108.56**	**107.00**	**37.36**	**73.87**	**13.45**
Coefficient of Variance	***2.23***	***3.59***	***5.88***	***1.41***	***5.31***	***2.75***
Age at testing (14 days)						
Cylinder #4	3660	4407	2649	4350	3084	878
Cylinder #5	3685	4952	2619	4598	3215	924
Cylinder #6	3493	4636	2820	4474	3181	851
Average	**3613**	**4665**	**2696**	**4474**	**3160**	**884**
Standard Deviation	**104.39**	**273.65**	**108.43**	**124.00**	**67.98**	**36.91**
Coefficient of Variance	***2.89***	***5.87***	***4.02***	***2.77***	***2.15***	***4.17***
Age at testing (28 days)						
Cylinder #7	4734	5407	4379	6964	5501	2695
Cylinder #8	4864	5621	4049	6669	5643	2760
Cylinder #9	4898	5366	4423	5656	5534	2693
Average	**4832**	**5465**	**4284**	**6430**	**5559**	**2716**
Standard Deviation	**86.56**	**136.93**	**204.41**	**686.06**	**74.31**	**38.12**
Coefficient of Variance	***1.79***	***2.51***	***4.77***	***10.67***	***1.34***	***1.40***
Age at testing (56 days)						
Cylinder #10	5223	5986	6346	7854	6979	3945
Cylinder #11	5552	6150	6571	8092	7532	4282
Cylinder #12	5590	5862	6517	8349	7240	4264
Average	**5455**	**5999**	**6478**	**8098**	**7250**	**4164**
Standard Deviation	**201.81**	**144.46**	**117.46**	**247.56**	**276.64**	**189.58**
Coefficient of Variance	***3.70***	***2.41***	***1.81***	***3.06***	***3.82***	***4.55***
Age at testing (90 days)						
Cylinder #13	5755	6473	7480	8400	8320	4463
Cylinder #14	6049	6633	7559	8237	8760	4771
Cylinder #15	5063	6381	7582	8633	8551	4369
Average	**5622**	**6496**	**7540**	**8423**	**8544**	**4534**
Standard Deviation	**506.21**	**127.52**	**53.50**	**199.03**	**220.09**	**210.28**
Coefficient of Variance	***9.00***	***1.96***	***0.71***	***2.36***	***2.58***	***4.64***

LTRC Lab. No.	C-3413	C-3423	C-3445	C-3451	C-3456	C-3474
Mixture ID	50TI-30G100S-20C	40TI-30G100S-30C	30TI-30G100S-40C	30TI-50G100S-20C	20TI-50G100S-30C	10TI-50G100S-40C
ASTM C 469, Static Modulus of Elasticity and Poisson's Ratio of Concrete in Compression (4x8 cylinders)						
Age at testing (7 days)						
Modulus						
Cylinder #2	4,050,000	4,000,000	3,250,000	3,750,000	3,150,000	2,250,000
Cylinder #3	3,750,000	4,150,000	3,600,000	3,800,000	3,350,000	2,450,000
Average	**3,900,000**	**4,075,000**	**3,425,000**	**3,775,000**	**3,250,000**	**2,350,000**
Standard Deviation	**212132.03**	**106066.02**	**247487.37**	**35355.34**	**141421.36**	**141421.36**
Coefficient of Variance	***5.44***	***2.60***	***7.23***	***0.94***	***4.35***	***6.02***
Poisson's Ratio						
Cylinder #2	0.20	0.17	0.15	0.18	0.25	0.34
Cylinder #3	0.20	0.21	0.16	0.18	0.21	0.50
Average	**0.20**	**0.19**	**0.16**	**0.18**	**0.23**	**0.42**
Standard Deviation	**0.00**	**0.03**	**0.01**	**0.00**	**0.03**	**0.11**
Coefficient of Variance	***0.00***	***14.89***	***4.56***	***0.00***	***12.30***	***26.94***
Age at testing (14 days)						
Modulus						
Cylinder #5	4,500,000	4,950,000	3,950,000	4,650,000	4,400,000	2,900,000
Cylinder #6	4,250,000	4,850,000	4,200,000	4,650,000	4,350,000	2,700,000
Average	**4,375,000**	**4,900,000**	**4,075,000**	**4,650,000**	**4,375,000**	**2,800,000**
Standard Deviation	**176776.70**	**70710.68**	**176776.70**	**0.00**	**35355.34**	**141421.36**
Coefficient of Variance	***4.04***	***1.44***	***4.34***	***0.00***	***0.81***	***5.05***
Poisson's Ratio						
Cylinder #5	0.20	0.10	0.16	0.21	0.21	0.28
Cylinder #6	0.21	0.13	0.13	0.21	0.15	0.21
Average	**0.21**	**0.12**	**0.15**	**0.21**	**0.18**	**0.25**
Standard Deviation	**0.01**	**0.02**	**0.02**	**0.00**	**0.04**	**0.05**
Coefficient of Variance	***3.45***	***18.45***	***14.63***	***0.00***	***23.57***	***20.20***
Age at testing (28 days)						
Modulus						
Cylinder #8	4,950,000	5,150,000	4,250,000	4,950,000	5,200,000	4,350,000
Cylinder #9	5,000,000	4,900,000	4,600,000	5,000,000	5,100,000	4,450,000
Average	**4,975,000**	**5,025,000**	**4,425,000**	**4,975,000**	**5,150,000**	**4,400,000**
Standard Deviation	**35355.34**	**176776.70**	**247487.37**	**35355.34**	**70710.68**	**70710.68**
Coefficient of Variance	***0.71***	***3.52***	***5.59***	***0.71***	***1.37***	***1.61***
Poisson's Ratio						
Cylinder #8	0.23	0.20	0.21	0.22	0.25	0.20
Cylinder #9	0.21	0.22	0.18	0.23	0.15	0.20
Average	**0.22**	**0.21**	**0.20**	**0.23**	**0.20**	**0.20**
Standard Deviation	**0.01**	**0.01**	**0.02**	**0.01**	**0.07**	**0.00**
Coefficient of Variance	***6.43***	***6.73***	***10.88***	***3.14***	***35.36***	***0.00***
Age at testing (90 days)						
Modulus						
Cylinder #14	5,500,000	5,500,000	5,750,000	5,800,000	5,750,000	5,100,000
Cylinder #15	5,000,000	5,650,000	5,900,000	5,700,000	5,750,000	5,050,000
Average	**5,250,000**	**5,575,000**	**5,825,000**	**5,750,000**	**5,750,000**	**5,075,000**
Standard Deviation	**353553.39**	**106066.02**	**106066.02**	**70710.68**	**0.00**	**35355.34**
Coefficient of Variance	***6.73***	***1.90***	***1.82***	***1.23***	***0.00***	***0.70***
Poisson's Ratio						
Cylinder #14	0.20	0.22	0.22	0.20	0.24	0.22
Cylinder #15	0.23	0.24	0.24	0.25	0.23	0.26
Average	**0.22**	**0.23**	**0.23**	**0.23**	**0.24**	**0.24**
Standard Deviation	**0.02**	**0.01**	**0.01**	**0.04**	**0.01**	**0.03**
Coefficient of Variance	***9.87***	***6.15***	***6.15***	***15.71***	***3.01***	***11.79***

LTRC Lab. No.	C-3413	C-3423	C-3445	C-3451	C-3456	C-3474
Mixture ID	50TI-30G100S-20C	40TI-30G100S-30C	30TI-30G100S-40C	30TI-50G100S-20C	20TI-50G100S-30C	10TI-50G100S-40C
ASTM C 78, Flexure Strength (psi), 6x6x20 beams						
Age at testing (7 days)						
Beam #1	560	598	474	540	384	17
Beam #2	595	609	474	572	345	17
Average	**578**	**604**	**474**	**556**	**365**	**17**
Standard Deviation	**24.75**	**7.78**	**0.00**	**22.63**	**27.58**	**0.00**
Coefficient of Variance	***4.29***	***1.29***	***0.00***	***4.07***	***7.57***	***0.00***
Age at testing (14 days)						
Beam #3	765	710	631	704	674	264
Beam #4	741	765	549	778	553	263
Average	**753**	**738**	**590**	**741**	**614**	**264**
Standard Deviation	**16.97**	**38.89**	**57.98**	**52.33**	**85.56**	**0.71**
Coefficient of Variance	***2.25***	***5.27***	***9.83***	***7.06***	***13.95***	***0.27***
Age at testing (28 days)						
Beam #5	984	838	679	1070	890	567
Beam #6	792	796	690	1063	903	629
Average	**888**	**817**	**685**	**1,067**	**897**	**598**
Standard Deviation	**135.76**	**29.70**	**7.78**	**4.95**	**9.19**	**43.84**
Coefficient of Variance	***15.29***	***3.64***	***1.14***	***0.46***	***1.03***	***7.33***
Age at testing (90 days)						
Beam #7	884	955	883	1190	936	650
Beam #8	925	968	865	1238	972	641
Average	**905**	**962**	**874**	**1,214**	**954**	**646**
Standard Deviation	**28.99**	**9.19**	**12.73**	**33.94**	**25.46**	**6.36**
Coefficient of Variance	***3.21***	***0.96***	***1.46***	***2.80***	***2.67***	***0.99***
ASTM C 157, Length Change of Hardened Concrete (air storage method)						
Percent Length Change 28 days air						
Beam #1	-0.0270	-0.0310	-0.0330	-0.0210	-0.0340	-0.0260
Beam #2	-0.0170	-0.0370	-0.0330	-0.0200	-0.0280	-0.0270
Average	**-0.0220**	**-0.0340**	**-0.0330**	**-0.0205**	**-0.0310**	**-0.0265**
Standard Deviation	**0.0071**	**0.0042**	**0.0000**	**0.0007**	**0.0042**	**0.0007**
Coefficient of Variance	***-32.14***	***-12.48***	***0.00***	***-3.45***	***-13.69***	***-2.67***
ASTM C 666, Freeze-Thaw Durability, 3x4x16 beams						
Age at testing (14 days)						
Beam #1	90.6	73.0	93.6	49.8	95.6	76.7
Beam #2	75.3	82.4	87.0	47.6	98.4	77.6
Beam #3	87.9	79.2	87.4	43.2	97.9	**77.2**
Average	**84.6**	**78.2**	**89.3**	**46.9**	**97.3**	**77.2**
Standard Deviation	**8.17**	**4.78**	**3.70**	**3.36**	**1.49**	**0.45**
Coefficient of Variance	***9.65***	***6.11***	***4.14***	***7.17***	***1.53***	***0.58***
ASTM C 1202, Rapid Chloride Permeability						
Coulombs at 56 days						
Sample #1	571	514	912	320	412	573
Sample #2	455	435	821	221	392	572
Sample #3	362	514	867	317	470	574
Sample #4	502	435	901	311	449	485
Average	**473**	**475**	**875**	**292**	**431**	**551**
Chloride Ion Penetrability	**Very Low**	**Very Low**	**Very Low**	**Very Low**	**Very Low**	**Very Low**
Standard Deviation	**87.73**	**45.61**	**40.93**	**47.65**	**35.25**	**44.01**
Coefficient of Variance	***18.57***	***9.61***	***4.68***	***16.30***	***8.18***	***7.99***

LTRC Lab. No.	C-3479	C-3485	C-3501	C-3534	C-3543	C-3547
Mixture ID	50TI-30G100S-20F	40TI-30G100S-30F	30TI-30G100S-40F	30TI-50G100S-20F	20TI-50G100S-30F	10TI-50G100S-40F
ASTM C 78, Flexure Strength (psi), 6x6x20 beams						
Age at testing (7 days)						
Beam #1	686	557	532	712	671	599
Beam #2	706	622	492	671	695	495
Average	**696**	**590**	**512**	**692**	**683**	**547**
Standard Deviation	**14.14**	**45.96**	**28.28**	**28.99**	**16.97**	**73.54**
Coefficient of Variance	***2.03***	***7.80***	***5.52***	***4.19***	***2.48***	***13.44***
Age at testing (14 days)						
Beam #3	823	728	720	784	776	679
Beam #4	809	789	684	872	864	642
Average	**816**	**759**	**702**	**828**	**820**	**661**
Standard Deviation	**9.90**	**43.13**	**25.46**	**62.23**	**62.23**	**26.16**
Coefficient of Variance	***1.21***	***5.69***	***3.63***	***7.52***	***7.59***	***3.96***
Age at testing (28 days)						
Beam #5	969	908	862	1,047	763	739
Beam #6	945	849	809	1,014	716	701
Average	**957**	**879**	**836**	**1,031**	**740**	**720**
Standard Deviation	**16.97**	**41.72**	**37.48**	**23.33**	**33.23**	**26.87**
Coefficient of Variance	***1.77***	***4.75***	***4.49***	***2.26***	***4.49***	***3.73***
Age at testing (90 days)						
Beam #7	882	933	968	1,107	1,130	765
Beam #8	893	823	904	848	1,013	814
Average	**888**	**878**	**936**	**978**	**1,072**	**790**
Standard Deviation	**7.78**	**77.78**	**45.25**	**183.14**	**82.73**	**34.65**
Coefficient of Variance	***0.88***	***8.86***	***4.83***	***18.74***	***7.72***	***4.39***
ASTM C 157, Length Change of Hardened Concrete (air storage method)						
Percent Length Change 28 days air						
Beam #1	-0.0260	-0.0215	-0.0170	-0.0070	-0.0060	-0.0080
Beam #2	-0.0220	-0.0200	-0.0155	-0.0050	-0.0065	-0.0080
Average	**-0.0240**	**-0.0208**	**-0.0163**	**-0.0060**	**-0.0063**	**-0.0080**
Standard Deviation	**0.0028**	**0.0011**	**0.0011**	**0.0014**	**0.0004**	**0.0000**
Coefficient of Variance	***-11.79***	***-5.11***	***-6.53***	***-23.57***	***-5.66***	***0.00***
ASTM C 666, Freeze-Thaw Durability, 3x4x16 beams						
Age at testing (14 days)						
Beam #1	84.4	90.8	54.2	61.7	32.0	39.6
Beam #2	81.9	87.8	52.6	54.8	22.2	--
Beam #3	91.2	89.9	47.2	--	--	--
Average	**85.8**	**89.5**	**51.3**	**58.3**	**27.1**	**--**
Standard Deviation	**4.81**	**1.54**	**3.67**	**4.88**	**6.93**	**--**
Coefficient of Variance	***5.61***	***1.72***	***7.15***	***8.38***	***25.57***	***--***
ASTM C 1202, Rapid Chloride Permeability						
Coulombs at 56 days						
Sample #1	474	389	348	350	147	141
Sample #2	494	310	355	338	233	128
Sample #3	274	357	293	416	234	141
Sample #4	316	336	284	289	205	154
Average	**390**	**348**	**320**	**348**	**205**	**141**
Chloride Ion Penetrability	**Very Low**	**Very Low**	**Very Low**	**Very Low**	**Very Low**	**Very Low**
Standard Deviation	**110.76**	**33.42**	**36.67**	**52.31**	**40.78**	**10.61**
Coefficient of Variance	***28.44***	***9.60***	***11.46***	***15.02***	***19.92***	***7.53***

LTRC Lab. No.	C-3555	C-3565	C-3578	C-3580	C-3614	C-3619
Mixture ID	50TI-30G120S-20C	40TI-30G120S-30C	30TI-30G120S-40C	30TI-50G120S-20C	20TI-50G120S-30C	10TI-50G120S-40C
Date Made	7/27/2010	8/4/2010	8/18/2010	8/25/2010	9/30/2010	10/6/2010
Type I Portland Cement (%)	50	40	30	30	20	10
Grade 100 Slag (%)						
Grade 120 Slag (%)	30	30	30	50	50	50
Class C Fly Ash (%)	20	30	40	20	30	40
Class F Fly Ash (%)						
Water Reducer (ZYLA 620 oz/100ct)	3.00	4.00	4.00	4.00	4.00	4.00
Air Entrainment (Daravair 1000 oz/100ct)	0.50	0.50	0.50	0.50	0.50	0.50
Fresh Concrete Tests						
Slump (inches)	1.00	1.50	1.00	2.00	3.00	4.00
Air Content (%)	3.20	3.30	3.40	3.60	3.50	2.90
Unit Weight (lbs/ft³)	149.20	148.80	149.20	148.40	146.80	148.80
Initial Set Time (hrs:mins)	5:28	7:58	8:36	7:02	9:35	8:33
Final Set Time (hrs:mins)	7:24	10:20	12:16	9:46	12:47	11:49
ASTM C 39, Compressive Strength (psi), 4x8 cyls.						
Age at testing (7 days)						
Cylinder #1	5664	4248	4601	5716	3752	74
Cylinder #2	5453	4571	5009	5512	3570	117
Cylinder #3	5644	4488	5091	6043	3831	121
Average	**5587**	**4436**	**4900**	**5757**	**3718**	**104**
Standard Deviation	**116.48**	**167.74**	**262.45**	**267.86**	**133.84**	**26.06**
Coefficient of Variance	***2.08***	***3.78***	***5.36***	***4.65***	***3.60***	***25.06***
Age at testing (14 days)						
Cylinder #4	7176	6208	6513	5915	5618	524
Cylinder #5	7196	5234	7019	7110	5573	546
Cylinder #6	7425	6218	6563	6082	5611	539
Average	**7266**	**5887**	**6698**	**6369**	**5601**	**536**
Standard Deviation	**138.35**	**565.25**	**278.83**	**647.13**	**24.21**	**11.24**
Coefficient of Variance	***1.90***	***9.60***	***4.16***	***10.16***	***0.43***	***2.10***
Age at testing (28 days)						
Cylinder #7	8415	7330	8092	7515	6799	2664
Cylinder #8	8863	7498	7973	7398	6932	2576
Cylinder #9	8468	7089	7729	8149	6608	2712
Average	**8582**	**7306**	**7931**	**7687**	**6780**	**2651**
Standard Deviation	**244.79**	**205.58**	**185.05**	**404.07**	**162.86**	**68.97**
Coefficient of Variance	***2.85***	***2.81***	***2.33***	***5.26***	***2.40***	***2.60***
Age at testing (56 days)						
Cylinder #10	9064	8325	8359	8407	6858	4295
Cylinder #11	9603	8042	8268	8014	7555	4590
Cylinder #12	8973	8384	8369	7541	7673	4281
Average	**9213**	**8250**	**8332**	**7987**	**7362**	**4389**
Standard Deviation	**340.51**	**182.82**	**55.65**	**433.62**	**440.45**	**174.50**
Coefficient of Variance	***3.70***	***2.22***	***0.67***	***5.43***	***5.98***	***3.98***
Age at testing (90 days)						
Cylinder #13	9742	8003	8837	8673	8539	5194
Cylinder #14	9233	8327	8985	8759	8682	5206
Cylinder #15	9606	8011	9548	7738	8009	4989
Average	**9527**	**8114**	**9123**	**8390**	**8410**	**5130**
Standard Deviation	**263.54**	**184.80**	**375.14**	**566.28**	**354.56**	**121.97**
Coefficient of Variance	***2.77***	***2.28***	***4.11***	***6.75***	***4.22***	***2.38***

LTRC Lab. No.	C-3555	C-3565	C-3578	C-3580	C-3614	C-3619
Mixture ID	50TI-30G120S-20C	40TI-30G120S-30C	30TI-30G120S-40C	30TI-50G120S-20C	20TI-50G120S-30C	10TI-50G120S-40C
ASTM C 469, Static Modulus of Elasticity and Poisson's Ratio of Concrete in Compression (4x8 cylinders)						
Age at testing (7 days)						
Modulus						
Cylinder #2	4,450,000	4,450,000	4,300,000	4,700,000	4,150,000	n/a
Cylinder #3	4,500,000	4,600,000	4,450,000	4,600,000	4,250,000	n/a
Average	**4,475,000**	**4,525,000**	**4,375,000**	**4,650,000**	**4,200,000**	
Standard Deviation	**35355.34**	**106066.02**	**106066.02**	**70710.68**	**70710.68**	
Coefficient of Variance	***0.79***	***2.34***	***2.42***	***1.52***	***1.68***	
Poisson's Ratio						
Cylinder #2	0.19	0.18	0.25	0.23	0.18	n/a
Cylinder #3	0.20	0.20	0.20	0.21	0.18	n/a
Average	**0.20**	**0.19**	**0.23**	**0.22**	**0.18**	
Standard Deviation	**0.01**	**0.01**	**0.04**	**0.01**	**0.00**	
Coefficient of Variance	***3.63***	***7.44***	***15.71***	***6.43***	***0.00***	
Age at testing (14 days)						
Modulus						
Cylinder #5	4,850,000	4,200,000	4,750,000	5,200,000	4,500,000	2,200,000
Cylinder #6	5,000,000	4,800,000	4,550,000	4,950,000	4,350,000	2,100,000
Average	**4,925,000**	**4,500,000**	**4,650,000**	**5,075,000**	**4,425,000**	**2,150,000**
Standard Deviation	**106066.02**	**424264.07**	**141421.36**	**176776.70**	**106066.02**	**70710.68**
Coefficient of Variance	***2.15***	***9.43***	***3.04***	***3.48***	***2.40***	***3.29***
Poisson's Ratio						
Cylinder #5	0.22	0.20	0.20	0.22	0.26	0.16
Cylinder #6	0.23	0.20	0.21	0.25	0.21	0.20
Average	**0.23**	**0.20**	**0.21**	**0.24**	**0.24**	**0.18**
Standard Deviation	**0.01**	**0.00**	**0.01**	**0.02**	**0.04**	**0.03**
Coefficient of Variance	***3.14***	***0.00***	***3.45***	***9.03***	***15.04***	***15.71***
Age at testing (28 days)						
Modulus						
Cylinder #8	5,150,000	5,300,000	5,400,000	5,600,000	4,950,000	4,150,000
Cylinder #9	5,400,000	4,850,000	5,000,000	5,550,000	4,850,000	4,400,000
Average	**5,275,000**	**5,075,000**	**5,200,000**	**5,575,000**	**4,900,000**	**4,275,000**
Standard Deviation	**176776.70**	**318198.05**	**282842.71**	**35355.34**	**70710.68**	**176776.70**
Coefficient of Variance	***3.35***	***6.27***	***5.44***	***0.63***	***1.44***	***4.14***
Poisson's Ratio						
Cylinder #8	0.20	0.19	0.23	0.25	0.22	0.16
Cylinder #9	0.26	0.19	0.22	0.24	0.23	0.12
Average	**0.23**	**0.19**	**0.23**	**0.25**	**0.23**	**0.14**
Standard Deviation	**0.04**	**0.00**	**0.01**	**0.01**	**0.01**	**0.03**
Coefficient of Variance	***18.45***	***0.00***	***3.14***	***2.89***	***3.14***	***20.20***
Age at testing (90 days)						
Modulus						
Cylinder #14	5,550,000	5,550,000	5,850,000	5,900,000	5,650,000	5,250,000
Cylinder #15	5,750,000	5,750,000	5,750,000	5,700,000	5,600,000	5,400,000
Average	**5,650,000**	**5,650,000**	**5,800,000**	**5,800,000**	**5,625,000**	**5,325,000**
Standard Deviation	**141421.36**	**141421.36**	**70710.68**	**141421.36**	**35355.34**	**106066.02**
Coefficient of Variance	***2.50***	***2.50***	***1.22***	***2.44***	***0.63***	***1.99***
Poisson's Ratio						
Cylinder #14	0.27	0.23	0.24	0.23	0.25	0.20
Cylinder #15	0.25	0.22	0.25	0.23	0.24	0.25
Average	**0.26**	**0.23**	**0.25**	**0.23**	**0.25**	**0.23**
Standard Deviation	**0.01**	**0.01**	**0.01**	**0.00**	**0.01**	**0.04**
Coefficient of Variance	***5.44***	***3.14***	***2.89***	***0.00***	***2.89***	***15.71***

LTRC Lab. No.	C-3555	C-3565	C-3578	C-3580	C-3614	C-3619
Mixture ID	50TI-30G120S-20C	40TI-30G120S-30C	30TI-30G120S-40C	30TI-50G120S-20C	20TI-50G120S-30C	10TI-50G120S-40C
ASTM C 78, Flexure Strength (psi), 6x6x20 beams						
Age at testing (7 days)						
Beam #1	737	912	704	808	586	52
Beam #2	726	804	798	937	669	55
Average	**732**	**858**	**751**	**873**	**628**	**54**
Standard Deviation	**7.78**	**76.37**	**66.47**	**91.22**	**58.69**	**2.12**
Coefficient of Variance	***1.06***	***8.90***	***8.85***	***10.45***	***9.35***	***3.97***
Age at testing (14 days)						
Beam #3	773	792	793	1,201	941	245
Beam #4	1,031	829	841	1,052	778	245
Average	**902**	**811**	**817**	**1,127**	**860**	**245**
Standard Deviation	**182.43**	**26.16**	**33.94**	**105.36**	**115.26**	**0.00**
Coefficient of Variance	***20.23***	***3.23***	***4.15***	***9.35***	***13.41***	***0.00***
Age at testing (28 days)						
Beam #5	1,163	1,052	973	1,447	999	557
Beam #6	1,014	911	914	1,053	706	499
Average	**1,089**	**982**	**944**	**1,250**	**853**	**528**
Standard Deviation	**105.36**	**99.70**	**41.72**	**278.60**	**207.18**	**41.01**
Coefficient of Variance	***9.68***	***10.16***	***4.42***	***22.29***	***24.30***	***7.77***
Age at testing (90 days)						
Beam #7	1,020	932	891	1,125	1,238	662
Beam #8	1,002	1,013	1,068	1,192	1,064	667
Average	**1,011**	**973**	**980**	**1,159**	**1,151**	**665**
Standard Deviation	**12.73**	**57.28**	**125.16**	**47.38**	**123.04**	**3.54**
Coefficient of Variance	***1.26***	***5.89***	***12.78***	***4.09***	***10.69***	***0.53***
ASTM C 157, Length Change of Hardened Concrete (air storage method)						
Percent Length Change 28 days air						
Beam #1	-0.0310	-0.0230	-0.0330	-0.0220	-0.0100	-0.0200
Beam #2	-0.0340	-0.0100	-0.0300	-0.0220	-0.0110	-0.0160
Average	**-0.0325**	**-0.0165**	**-0.0315**	**-0.0220**	**-0.0105**	**-0.0180**
Standard Deviation	**0.0021**	**0.0092**	**0.0021**	**0.0000**	**0.0007**	**0.0028**
Coefficient of Variance	***-6.53***	***-55.71***	***-6.73***	***0.00***	***-6.73***	***-15.71***
ASTM C 666, Freeze-Thaw Durability, 3x4x16 beams						
Age at testing (14 days)						
Beam #1	76.7	93.3	87.7	85.6	83.5	76.4
Beam #2	83.0	88.1	87.7	84.1	76.9	82.1
Beam #3	75.5	84.9	89.7	87.2	80.2	--
Average	**78.4**	**88.8**	**88.4**	**85.6**	**80.2**	**79.3**
Standard Deviation	**4.03**	**4.24**	**1.15**	**1.55**	**3.30**	**4.03**
Coefficient of Variance	***5.14***	***4.78***	***1.31***	***1.81***	***4.11***	***5.09***
ASTM C 1202, Rapid Chloride Permeability						
Coulombs at 56 days						
Sample #1	738	479	371	329	384	736
Sample #2	684	552	428	340	336	709
Sample #3	851	427	388	381	396	723
Sample #4	788	345	418	373	378	737
Average	**765**	**451**	**401**	**356**	**374**	**726**
Chloride Ion Penetrability	**Very Low**	**Very Low**	**Very Low**	**Very Low**	**Very Low**	**Very Low**
Standard Deviation	**71.22**	**87.17**	**26.37**	**25.16**	**26.10**	**13.15**
Coefficient of Variance	***9.31***	***19.34***	***6.57***	***7.07***	***6.99***	***1.81***

LTRC Lab. No.	C-3627	C-3668	C-3671	C-3694	C-3726	C-3729
Mixture ID	50TI-30G120S-20F	40TI-30G120S-30F	30TI-30G120S-40F	30TI-50G120S-20F	20TI-50G120S-30F	10TI-50G120S-40F
Date Made	10/26/2010	11/30/2010	12/9/2011	1/12/2011	2/16/2011	2/21/2011
Type I Portland Cement (%)	50	40	30	30	20	10
Grade 100 Slag (%)						
Grade 120 Slag (%)	30	30	30	50	50	50
Class C Fly Ash (%)						
Class F Fly Ash (%)	20	30	40	20	30	40
Water Reducer (ZYLA 620 oz/100ct)	4.00	4.00	4.00	4.00	4.00	4.00
Air Entrainment (Daravair 1000 oz/100ct)	0.50	0.50	0.50	0.50	0.50	0.50
Fresh Concrete Tests						
Slump (inches)	2.50	1.50	3.25	1.50	0.50	7.50
Air Content (%)	3.60	2.90	4.00	3.70	4.40	3.40
Unit Weight (lbs/ft³)	147.80	147.60	146.60	147.80	145.60	145.60
Initial Set Time (hrs:mins)	6:06	6:15	8:12	8:02	8:16	15:25
Final Set Time (hrs:mins)	8:13	8:59	11:17	11:23	13:49	30:27
ASTM C 39, Compressive Strength (psi), 4x8 cyls.						
Age at testing (7 days)						
Cylinder #1	4867	3986	2882	4114	2713	2285
Cylinder #2	5118	3981	3060	4025	2806	2133
Cylinder #3	4405	3959	2760	3962	2830	2338
Average	**4797**	**3975**	**2901**	**4034**	**2783**	**2252**
Standard Deviation	**361.67**	**14.36**	**150.87**	**76.37**	**61.80**	**106.41**
Coefficient of Variance	***7.54***	***0.36***	***5.20***	***1.89***	***2.22***	***4.73***
Age at testing (14 days)						
Cylinder #4	5753	5286	4170	5500	3935	2835
Cylinder #5	6001	5299	4089	5270	4020	2835
Cylinder #6	5287	5622	3908	6262	4036	2855
Average	**5680**	**5402**	**4056**	**5677**	**3997**	**2842**
Standard Deviation	**362.50**	**190.35**	**134.14**	**519.23**	**54.29**	**11.55**
Coefficient of Variance	***6.38***	***3.52***	***3.31***	***9.15***	***1.36***	***0.41***
Age at testing (28 days)						
Cylinder #7	6471	6270	4779	6181	4595	3589
Cylinder #8	6964	5414	4589	6107	5005	3569
Cylinder #9	7062	6343	5126	6653	4878	3454
Average	**6832**	**6009**	**4831**	**6314**	**4826**	**3537**
Standard Deviation	**316.74**	**516.58**	**272.30**	**296.19**	**209.89**	**72.86**
Coefficient of Variance	***4.64***	***8.60***	***5.64***	***4.69***	***4.35***	***2.06***
Age at testing (56 days)						
Cylinder #10	6963	6704	5476	7153	5082	3733
Cylinder #11	7249	6830	5242	7478	5418	3659
Cylinder #12	7159	7112	5482	7538	5110	3849
Average	**7124**	**6882**	**5400**	**7390**	**5203**	**3747**
Standard Deviation	**146.24**	**208.91**	**136.86**	**207.14**	**186.43**	**95.77**
Coefficient of Variance	***2.05***	***3.04***	***2.53***	***2.80***	***3.58***	***2.56***
Age at testing (90 days)						
Cylinder #13	7189	7119	5931	6752	5021	4035
Cylinder #14	7285	7147	6183	7355	4953	3910
Cylinder #15	7321	7115	6071	7753	5723	4156
Average	**7265**	**7127**	**6062**	**7287**	**5232**	**4034**
Standard Deviation	**68.23**	**17.44**	**126.26**	**503.99**	**426.29**	**123.01**
Coefficient of Variance	***0.94***	***0.24***	***2.08***	***6.92***	***8.15***	***3.05***

LTRC Lab. No.	C-3627	C-3668	C-3671	C-3694	C-3726	C-3729
Mixture ID	50TI-30G120S-20F	40TI-30G120S-30F	30TI-30G120S-40F	30TI-50G120S-20F	20TI-50G120S-30F	10TI-50G120S-40F
ASTM C 469, Static Modulus of Elasticity and Poisson's Ratio of Concrete in Compression (4x8 cylinders)						
Age at testing (7 days)						
Modulus						
Cylinder #2	4,040,000	4,750,000	4,600,000	4,550,000	4,450,000	3,500,000
Cylinder #3	4,740,000	4,400,000	4,300,000	4,550,000	4,150,000	3,700,000
Average	**4,390,000**	**4,575,000**	**4,450,000**	**4,550,000**	**4,300,000**	**3,600,000**
Standard Deviation	**494974.75**	**247487.37**	**212132.03**	**0.00**	**212132.03**	**141421.36**
Coefficient of Variance	***11.28***	***5.41***	***4.77***	***0.00***	***4.93***	***3.93***
Poisson's Ratio						
Cylinder #2	0.18	0.22	0.21	0.17	0.21	0.20
Cylinder #3	0.19	0.19	0.20	0.20	0.22	0.25
Average	**0.19**	**0.21**	**0.21**	**0.19**	**0.22**	**0.23**
Standard Deviation	**0.01**	**0.02**	**0.01**	**0.02**	**0.01**	**0.04**
Coefficient of Variance	***3.82***	***10.35***	***3.45***	***11.47***	***3.29***	***15.71***
Age at testing (14 days)						
Modulus						
Cylinder #5	5,050,000	4,850,000	4,700,000	5,000,000	4,550,000	4,150,000
Cylinder #6	4,850,000	4,950,000	4,100,000	4,850,000	4,900,000	4,350,000
Average	**4,950,000**	**4,900,000**	**4,400,000**	**4,925,000**	**4,725,000**	**4,250,000**
Standard Deviation	**141421.36**	**70710.68**	**424264.07**	**106066.02**	**247487.37**	**141421.36**
Coefficient of Variance	***2.86***	***1.44***	***9.64***	***2.15***	***5.24***	***3.33***
Poisson's Ratio						
Cylinder #5	0.21	0.20	0.22	0.26	0.23	0.22
Cylinder #6	0.21	0.21	0.20	0.24	0.23	0.25
Average	**0.21**	**0.21**	**0.21**	**0.25**	**0.23**	**0.24**
Standard Deviation	**0.00**	**0.01**	**0.01**	**0.01**	**0.00**	**0.02**
Coefficient of Variance	***0.00***	***3.45***	***6.73***	***5.66***	***0.00***	***9.03***
Age at testing (28 days)						
Modulus						
Cylinder #8	5,300,000	5,150,000	4,750,000	5,100,000	4,900,000	4,250,000
Cylinder #9	5,200,000	5,500,000	4,850,000	5,150,000	4,750,000	4,350,000
Average	**5,250,000**	**5,325,000**	**4,800,000**	**5,125,000**	**4,825,000**	**4,300,000**
Standard Deviation	**70710.68**	**247487.37**	**70710.68**	**35355.34**	**106066.02**	**70710.68**
Coefficient of Variance	***1.35***	***4.65***	***1.47***	***0.69***	***2.20***	***1.64***
Poisson's Ratio						
Cylinder #8	0.22	0.24	0.22	0.23	0.21	0.24
Cylinder #9	0.24	0.25	0.23	0.23	0.24	0.20
Average	**0.23**	**0.25**	**0.23**	**0.23**	**0.23**	**0.22**
Standard Deviation	**0.01**	**0.01**	**0.01**	**0.00**	**0.02**	**0.03**
Coefficient of Variance	***6.15***	***2.89***	***3.14***	***0.00***	***9.43***	***12.86***
Age at testing (90 days)						
Modulus						
Cylinder #14	5,800,000	5,800,000	5,600,000	5,550,000	4,750,000	4,700,000
Cylinder #15	5,950,000	6,050,000	5,650,000	5,800,000	4,850,000	4,850,000
Average	**5,875,000**	**5,925,000**	**5,625,000**	**5,675,000**	**4,800,000**	**4,775,000**
Standard Deviation	**106066.02**	**176776.70**	**35355.34**	**176776.70**	**70710.68**	**106066.02**
Coefficient of Variance	***1.81***	***2.98***	***0.63***	***3.12***	***1.47***	***2.22***
Poisson's Ratio						
Cylinder #14	0.23	0.20	0.22	0.23	0.21	0.21
Cylinder #15	0.24	0.22	0.22	0.24	0.20	0.26
Average	**0.24**	**0.21**	**0.22**	**0.24**	**0.21**	**0.24**
Standard Deviation	**0.01**	**0.01**	**0.00**	**0.01**	**0.01**	**0.04**
Coefficient of Variance	***3.89***	***6.73***	***0.00***	***3.01***	***3.45***	***15.04***

LTRC Lab. No.	C-3627	C-3668	C-3671	C-3694	C-3726	C-3729
Mixture ID	50TI-30G120S-20F	40TI-30G120S-30F	30TI-30G120S-40F	30TI-50G120S-20F	20TI-50G120S-30F	10TI-50G120S-40F
ASTM C 78, Flexure Strength (psi), 6x6x20 beams						
Age at testing (7 days)						
Beam #1	740	711	588	774	556	454
Beam #2	694	760	567	600	665	499
Average	**717**	**736**	**578**	**687**	**611**	**477**
Standard Deviation	**32.53**	**34.65**	**14.85**	**123.04**	**77.07**	**31.82**
Coefficient of Variance	***4.54***	***4.71***	***2.57***	***17.91***	***12.62***	***6.68***
Age at testing (14 days)						
Beam #3	868	912	801	807	767	583
Beam #4	941	775	708	910	747	533
Average	**905**	**844**	**755**	**859**	**757**	**558**
Standard Deviation	**51.62**	**96.87**	**65.76**	**72.83**	**14.14**	**35.36**
Coefficient of Variance	***5.71***	***11.48***	***8.72***	***8.48***	***1.87***	***6.34***
Age at testing (28 days)						
Beam #5	1,058	938	745	1,084	873	521
Beam #6	972	890	920	954	813	655
Average	**1,015**	**914**	**833**	**1,019**	**843**	**588**
Standard Deviation	**60.81**	**33.94**	**123.74**	**91.92**	**42.43**	**94.75**
Coefficient of Variance	***5.99***	***3.71***	***14.86***	***9.02***	***5.03***	***16.11***
Age at testing (90 days)						
Beam #7	1,053	1,152	1,027	863	823	630
Beam #8	1,069	1,067	916	946	912	718
Average	**1,061**	**1,110**	**972**	**905**	**868**	**674**
Standard Deviation	**11.31**	**60.10**	**78.49**	**58.69**	**62.93**	**62.23**
Coefficient of Variance	***1.07***	***5.42***	***8.08***	***6.49***	***7.25***	***9.23***
ASTM C 157, Length Change of Hardened Concrete (air storage method)						
Percent Length Change 28 days air						
Beam #1	-0.0170	-0.0100	-0.0120	-0.0110	-0.0120	-0.0190
Beam #2	-0.0240	-0.0180	-0.0130	-0.0095	-0.0140	-0.0190
Average	**-0.0205**	**-0.0140**	**-0.0125**	**-0.0103**	**-0.0130**	**-0.0190**
Standard Deviation	**0.0049**	**0.0057**	**0.0007**	**0.0011**	**0.0014**	**0.0000**
Coefficient of Variance	***-24.15***	***-40.41***	***-5.66***	***-10.35***	***-10.88***	***0.00***
ASTM C 666, Freeze-Thaw Durability, 3x4x16 beams						
Age at testing (14 days)						
Beam #1	83.4	79.0	79.5	44.8	54.2	28.8
Beam #2	86.9	73.3	82.4	57.6	57.4	28.8
Beam #3	87.5	--	87.5	57.4	51.4	28.4
Average	**85.9**	**76.2**	**83**	**53**	**54**	**29**
Standard Deviation	**2.21**	**4.03**	**4.05**	**7.33**	**3.00**	**0.23**
Coefficient of Variance	***2.58***	***5.29***	***4.87***	***13.77***	***5.53***	***0.81***
ASTM C 1202, Rapid Chloride Permeability						
Coulombs at 56 days						
Sample #1	620	502	328	361	274	217
Sample #2	602	533	448	400	251	236
Sample #3	548	490	477	435	239	226
Sample #4	666	605	559	357	248	263
Average	**609**	**533**	**453**	**388**	**253**	**236**
Chloride Ion Penetrability	**Very Low**	**Very Low**	**Very Low**	**Very Low**	**Very Low**	**Very Low**
Standard Deviation	**48.79**	**51.62**	**95.68**	**36.71**	**14.90**	**19.91**
Coefficient of Variance	***8.01***	***9.69***	***21.12***	***9.46***	***5.89***	***8.45***

LTRC Lab. No.	C-3750	C-3764	C-3785
Mixture ID	60TI-20C-20F	40TI-30C-30F	20TI-40C-40F
Date Made	3/1/2011	3/16/2011	3/23/2011
Type I Portland Cement (%)	60	40	20
Class C Fly Ash (%)	20	30	40
Class F Fly Ash (%)	20	30	40
Water Reducer (ZYLA 620 oz/100ct)	4.00	4.00	4.00
Air Entrainment (Daravair 1000 oz/100ct)	0.50	0.50	0.50
Fresh Concrete Tests			
Slump (inches)	5.50	6.00	8.50
Air Content (%)	5.10	5.40	4.20
Unit Weight (lbs/ft³)	144.40	143.20	144.00
Initial Set Time (hrs:mins)	9:31	11:35	13:25
Final Set Time (hrs:mins)	11:34	15:05	37:10
ASTM C 39, Compressive Strength (psi), 4x8 cyls.			
Age at testing (7 days)			
Cylinder #1	3813	2052	676
Cylinder #2	4101	2119	789
Cylinder #3	4080	2044	709
Average	**3998**	**2072**	**725**
Standard Deviation	**160.56**	**41.19**	**58.11**
Coefficient of Variance	***4.02***	***1.99***	***8.02***
Age at testing (14 days)			
Cylinder #4	3889	3017	1286
Cylinder #5	4180	2913	1145
Cylinder #6	4159	2934	1282
Average	**4076**	**2955**	**1238**
Standard Deviation	**162.29**	**54.99**	**80.28**
Coefficient of Variance	***3.98***	***1.86***	***6.49***
Age at testing (28 days)			
Cylinder #7	5639	3766	1601
Cylinder #8	5720	3529	1667
Cylinder #9	6061	3614	1739
Average	**5807**	**3636**	**1669**
Standard Deviation	**223.95**	**120.07**	**69.02**
Coefficient of Variance	***3.86***	***3.30***	***4.14***
Age at testing (56 days)			
Cylinder #10	6412	4941	2229
Cylinder #11	6769	4895	2124
Cylinder #12	6711	4873	2268
Average	**6631**	**4903**	**2207**
Standard Deviation	**191.58**	**34.70**	**74.48**
Coefficient of Variance	***2.89***	***0.71***	***3.37***
Age at testing (90 days)			
Cylinder #13	7042	5265	2569
Cylinder #14	6954	5272	2844
Cylinder #15	7200	5194	2268
Average	**7065**	**5244**	**2560**
Standard Deviation	**124.65**	**43.15**	**288.10**
Coefficient of Variance	***1.76***	***0.82***	***11.25***

LTRC Lab. No.	C-3750	C-3764	C-3785
Mixture ID	60TI-20C-20F	40TI-30C-30F	20TI-40C-40F
ASTM C 469, Static Modulus of Elasticity and Poisson's Ratio of Concrete in Compression (4x8 cy			
Age at testing (7 days)			
Modulus			
Cylinder #2	4,300,000	3,600,000	2,850,000
Cylinder #3	4,300,000	3,650,000	3,100,000
Average	**4,300,000**	**3,625,000**	**2,975,000**
Standard Deviation	**0.00**	**35355.34**	**176776.70**
Coefficient of Variance	***0.00***	***0.98***	***5.94***
Poisson's Ratio			
Cylinder #2	0.20	0.21	0.21
Cylinder #3	0.20	0.21	0.24
Average	**0.20**	**0.21**	**0.23**
Standard Deviation	**0.00**	**0.00**	**0.02**
Coefficient of Variance	***0.00***	***0.00***	***9.43***
Age at testing (14 days)			
Modulus			
Cylinder #5	4,500,000	5,500,000	3,350,000
Cylinder #6	4,400,000	4,000,000	3,200,000
Average	**4,450,000**	**4,750,000**	**3,275,000**
Standard Deviation	**70710.68**	**1060660.17**	**106066.02**
Coefficient of Variance	***1.59***	***22.33***	***3.24***
Poisson's Ratio			
Cylinder #5	0.21	0.28	0.19
Cylinder #6	0.20	0.21	0.20
Average	**0.21**	**0.25**	**0.20**
Standard Deviation	**0.01**	**0.05**	**0.01**
Coefficient of Variance	***3.45***	***20.20***	***3.63***
Age at testing (28 days)			
Modulus			
Cylinder #8	5,000,000	4,300,000	3,150,000
Cylinder #9	5,050,000	4,350,000	3,250,000
Average	**5,025,000**	**4,325,000**	**3,200,000**
Standard Deviation	**35355.34**	**35355.34**	**70710.68**
Coefficient of Variance	***0.70***	***0.82***	***2.21***
Poisson's Ratio			
Cylinder #8	0.22	0.21	0.18
Cylinder #9	0.22	0.22	0.21
Average	**0.22**	**0.22**	**0.20**
Standard Deviation	**0.00**	**0.01**	**0.02**
Coefficient of Variance	***0.00***	***3.29***	***10.88***
Age at testing (90 days)			
Modulus			
Cylinder #14	5,550,000	5,050,000	4,150,000
Cylinder #15	5,700,000	4,950,000	4,500,000
Average	**5,625,000**	**5,000,000**	**4,325,000**
Standard Deviation	**106066.02**	**70710.68**	**247487.37**
Coefficient of Variance	***1.89***	***1.41***	***5.72***
Poisson's Ratio			
Cylinder #14	0.23	0.23	0.17
Cylinder #15	0.23	0.25	0.21
Average	**0.23**	**0.24**	**0.19**
Standard Deviation	**0.00**	**0.01**	**0.03**
Coefficient of Variance	***0.00***	***5.89***	***14.89***

LTRC Lab. No.	C-3750	C-3764	C-3785
Mixture ID	60TI-20C-20F	40TI-30C-30F	20TI-40C-40F
ASTM C 78, Flexure Strength (psi), 6x6x20 beams			
Age at testing (7 days)			
Beam #1	690	515	274
Beam #2	676	531	272
Average	**683**	**523**	**273**
Standard Deviation	**9.90**	**11.31**	**1.41**
Coefficient of Variance	***1.45***	***2.16***	***0.52***
Age at testing (14 days)			
Beam #3	690	506	328
Beam #4	684	543	340
Average	**687**	**525**	**334**
Standard Deviation	**4.24**	**26.16**	**8.49**
Coefficient of Variance	***0.62***	***4.99***	***2.54***
Age at testing (28 days)			
Beam #5	769	546	343
Beam #6	717	584	390
Average	**743**	**565**	**367**
Standard Deviation	**36.77**	**26.87**	**33.23**
Coefficient of Variance	***4.95***	***4.76***	***9.07***
Age at testing (90 days)			
Beam #7	944	806	556
Beam #8	712	805	513
Average	**828**	**806**	**535**
Standard Deviation	**164.05**	**0.71**	**30.41**
Coefficient of Variance	***19.81***	***0.09***	***5.69***
ASTM C 157, Length Change of Hardened Concrete (air storage method)			
Percent Length Change 28 days air			
Beam #1	-0.0260	-0.0230	-0.0200
Beam #2	-0.0230	-0.0260	-0.0130
Average	**-0.0245**	**-0.0245**	**-0.0165**
Standard Deviation	**0.0021**	**0.0021**	**0.0049**
Coefficient of Variance	***-8.66***	***-8.66***	***-30.00***
ASTM C 666, Freeze-Thaw Durability, 3x4x16 beams			
Age at testing (14 days)			
Beam #1	90.4	96.7	74.7
Beam #2	91.5	97.2	73.7
Beam #3			
Average	**91**	**97**	**74**
Standard Deviation	**0.78**	**0.35**	**0.71**
Coefficient of Variance	***0.86***	***0.36***	***0.95***
ASTM C 1202, Rapid Chloride Permeability			
Coulombs at 28 days			
Sample #1	2497	4896	7247
Sample #2	2338	5673	8049
Sample #3	2297	4447	8508
Sample #4	2566	3692	9287
Average	**2425**	**4677**	**8273**
Chloride Ion Penetrability	**Moderate**	**High**	**High**
Standard Deviation	**127.82**	**829.28**	**853.67**
Coefficient of Variance	***5.27***	***17.73***	***10.32***
Coulombs at 56 days			
Sample #1	4,537	2,136	917
Sample #2	4,124	1,826	826
Sample #3	4,375	2,214	971
Average	**4345**	**2059**	**905**
Chloride Ion Penetrability	**High**	**Moderate**	**Very Low**
Standard Deviation	**208.09**	**205.23**	**73.28**
Coefficient of Variance	***4.79***	***9.97***	***8.10***