Louisiana's Laboratory Experience with Type IL Portland Cement

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ABSTRACT
Portland cement concrete (PCC) is the world's most versatile and most used construction material. A new method of reducing the carbon footprint and increasing the sustainability of PCC has emerged that incorporates a much larger portion of interground limestone (Type IL cement) into the cement. The objectives of this research were to characterize the fresh and hardened concrete properties of binary and ternary combinations incorporating Type IL cement. Three binary and three ternary mixtures were prepared and tested for both fresh and hardened characteristics. Concrete samples were produced in laboratory conditions with a w/cm ratio of 0.45. Fresh concrete properties measured included: slump, unit weight, air content, and set time. Hardened concrete properties measured included: compressive strength, flexural strength, surface resistivity, freeze-thaw durability, and shrinkage. The results of this study showed that the use of Type IL portland cement in Louisiana should be allowed for all applications including ternary mixtures up to 70 percent replacement. Compressive and flexural strength results were comparable. Type IL mixtures exhibited less shrinkage when compared to the control mixtures with Type I cement. Surface resistivity results were comparable and indicated that the surface resistivity meter use will be applicable for mixtures containing Type IL cement. Based upon the results of the study, the authors recommend that Type IL cements be allowed for all uses in Louisiana.

INTRODUCTION

Portland cement concrete (PCC) is the world's most versatile and most used construction material. Modern concrete consists of six main ingredients: coarse aggregate, sand, portland cement, supplementary cementitious materials (SCMs), chemical admixtures, and water. 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 SCMs to increase pavement durability while lowering the initial and life-cycle cost. Additionally, a new method of reducing the carbon footprint and increasing the sustainability of PCC has emerged that incorporates a much larger portion of interground limestone into the cement.

ASTM and AASHTO have now changed specification language of ASTM C595 (*1*) and AASHTO M240 (*2*) to allow up to 15 percent use of interground limestone. The incorporation of the increased limestone content significantly reduces the carbon dioxide (CO_2) footprint of the resultant PCC (*3*) while extending the life of cement quarries (*4*). The use of these cements is widespread in Europe and much of the research work can be found in state-of-the-art reports (4-*6*). Barrett et al. noted that portland limestone cement (PLC) and ordinary portland cement (OPC) has similar mechanical performance with restrained ring shrinkage behavior of the PLC being similar as well (*7*). They also noted that PLC appeared to meet specifications and should be used interchangeably with Type I portland cement.

Several states have conducted field trials or currently allow the use of PLC including Utah, Oklahoma, and Iowa (*8*). Work is also ongoing at the University of Toronto and University of New Brunswick looking at low temperature sulfate attack, potential interaction with deicers, and early age shrinkage cracking potential (*9-10*). Work by Holcim has also shown the potential for further synergistic action of ternary cementitious systems that contain Type IL cement (*11*).

Recently the Louisiana Department of Transportation and Development (LADOTD) has implemented the use of ternary mixtures for both structural and paving concrete applications at the rate of 70 and 50 percent replacement of cement, respectively. A concern arose with the introduction of Type IL cement as to whether the new specifications would need revision. This project was initiated to address those concerns.

The objectives of this research were to characterize the fresh and hardened concrete properties of binary and ternary combinations incorporating Type IL cement. Three binary and three ternary mixtures were prepared and tested for both fresh and hardened characteristics. Mixtures from a previous ternary mixture study were used as control mixtures for comparison purposes due to the same materials being used for each study. Additionally the same clinker source was used for both studies. Concrete samples were produced in laboratory conditions with a w/cm ratio of 0.45. Fresh concrete properties measured included: slump, unit weight, air content, and set time. Hardened concrete properties measured included: compressive strength, flexural strength, surface resistivity, freeze-thaw durability, and free shrinkage.

MATERIALS AND TEST METHODS

Concrete Samples

The concrete samples used in this study were produced at the LTRC concrete research laboratory. Six mixture designs were developed using various combinations of Type IL cement and supplemental cementitious materials. Table 1 shows the mixture proportions for each design; the mixture names represent the percentage blend of cementitious materials and are used throughout the paper. The coarse and fine aggregate used in the mixtures were #67 limestone and natural river sand, respectively. All mixtures were designed with a 0.45 water-to-cement ratio and air entraining (vinsol resin) and super plasticizer (polycarboxylate) admixtures were also used. All concrete samples were cured according to ASTM C192 (*12*). Note that the control Type I cement mixtures and the Type IL cement mixtures were produced with cement from the same clinker source. The grade 120 slag and both the class C and class F fly ash sources were the same for both sets of mixtures.

TABLE 1 Mixture Proportions for All Concrete Mixtures*

Mixture Name	Type IL Cement (lb/yd^3)	Grade 120 Slag (lb/yd^3)	Class C Fly Ash (lb/yd^3)	Class F Fly Ash (lb/yd^3)	Water (lb/yd^3)	Coarse Aggr. (lb/yd^3)	Fine Aggr. (lb/yd^3)
80TIL-20C	400		100		225	2072	1354
80TIL-20F	400			100	225	1951	1243
50TIL-50S	250	250			225	1945	1260
30TIL-30S-40C	150	150	200		225	1949	1232
30TIL-30S-40F	150	150		200	225	1947	1211
40TIL-30C-30F	200		150	150	225	1951	1215

Note that all control mixtures were identical and information on them can be found here (13)

Test Methods

The test factorial and all testing was performed with triplicate specimens with the exception of set time, slump, and air content. Set times were determined according to ASTM C403 (*14*). Compression strength testing was performed at 7, 14, 28, 56, and 90 days of age following ASTM C39 (*15*). Separate cylinders were made for surface resistivity testing at 28-days of age according to DOTD TR 233 (*16*). Flexure strength testing was performed at 28-days of age following ASTM C78 (*17*). Length change testing was also performed according to ASTM C157M (*18*). Slump and air content were measured according to ASTM C143 (*19*) and ASTM C231 (*20*), respectively.

RESULTS AND DISCUSSION

The fresh concrete properties are shown in Table 2. The fresh properties showed a very high air content and low unit weight for the 80TIL-20C mixture, which was caused by a higher than normal dosage of air entraining admixture. The mixture would have been repeated if a sufficient amount of IL cement were remaining after completion of the study. Generally speaking, the mixtures produced with the Type IL cement showed similar results to the mixtures produced with the Type I cement for slump, air content, and unit weight. The variability of air content within the results suggested that strength may be influenced, but in general, strengths were not significantly affected.

Figure 1 shows the intial and final set times for all mixtures. The set times for the 80-20 IL mixture are missing due to oversight during the mixing and sample casting process. It is important to note that for a high volume fly ash mixture such as the 40-30-30, the set times were significantly reduced offsetting the tendancy of the fly ash to delay set time. This may be due to the finer grind of the IL cement offsetting the set delay due to ash addition. The results were comparable for other mixtures studied.

TABLE 2 Fresh Properties for All Concrete Mixtures

Mixture Name	Slump (in.)	Air (%)	Unit Weight (lb/ft^3)
80TI-20C	5.00	6.0	144.0
80TIL-20C	3.75	11.0	135.7
80TI-20F	5.00	5.8	144.0
80TIL-20F	4.75	3.8	147.3
50TI-50G120S	4.00	5.1	144.2
50TIL-50G120S	0.50	3.3	147.0
30TI-30G120S-40C	1.00	3.4	149.2
30TIL-30G120S-40C	7.50	1.7	150.1
30TI-30G120S040F	3.25	4.0	146.6
30TIL-30G120S-40F	7.75	3.9	146.7
40TI-30C-30F	6.00	5.4	143.2
40TIL-30C-30F	5.25	4.5	149.7

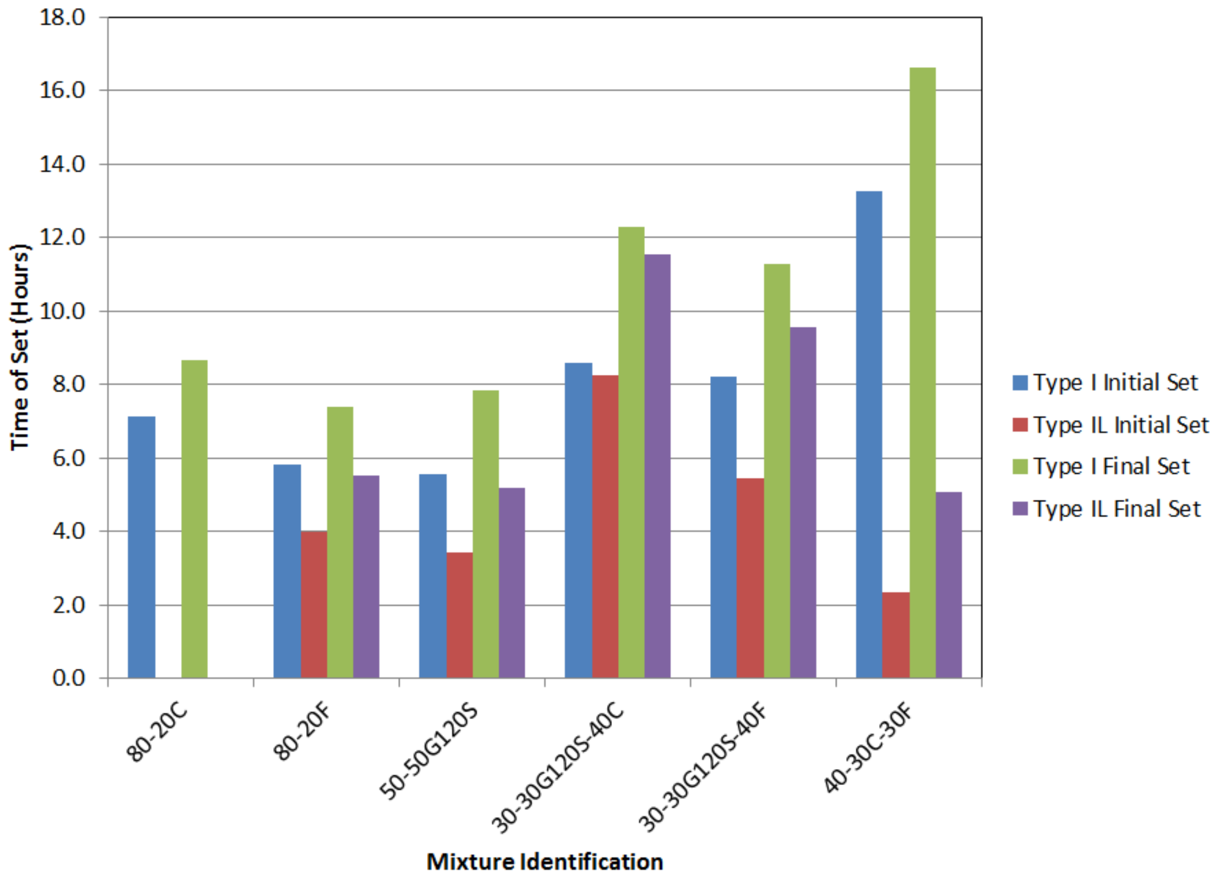

FIGURE 1 Initial and final setting times of mixtures.

Figure 2 shows the average compressive strength gain results for the binary mixtures. Note that the mixtures contianing the Type IL cement equaled or exceeded the strengths for companion mixtures containing the Type I cement. This is expecially true at earlier ages between 7 and 28 days.

Figure 3 shows the average compressive strength gain results for the ternary mixtures. The Type IL cement mixtures showed equal performance at early ages for ternary mixtures containing slag but tended to slightly exceed strengths for companion mixtures at later ages, expecially for the ternary mixture continaing class C fly ash. The 40-30-30 mixtures show the most improvement with about a 10 percent increase in strength when comparing the Type IL and the Type I cement mixtures. This shows that the Type IL cements interact very favorably with the combinations of class C and F fly ash used in this study, and improved the 28-day strengths above 4000 psi which is a generally accepted level for many DOT structural concrete specifications.

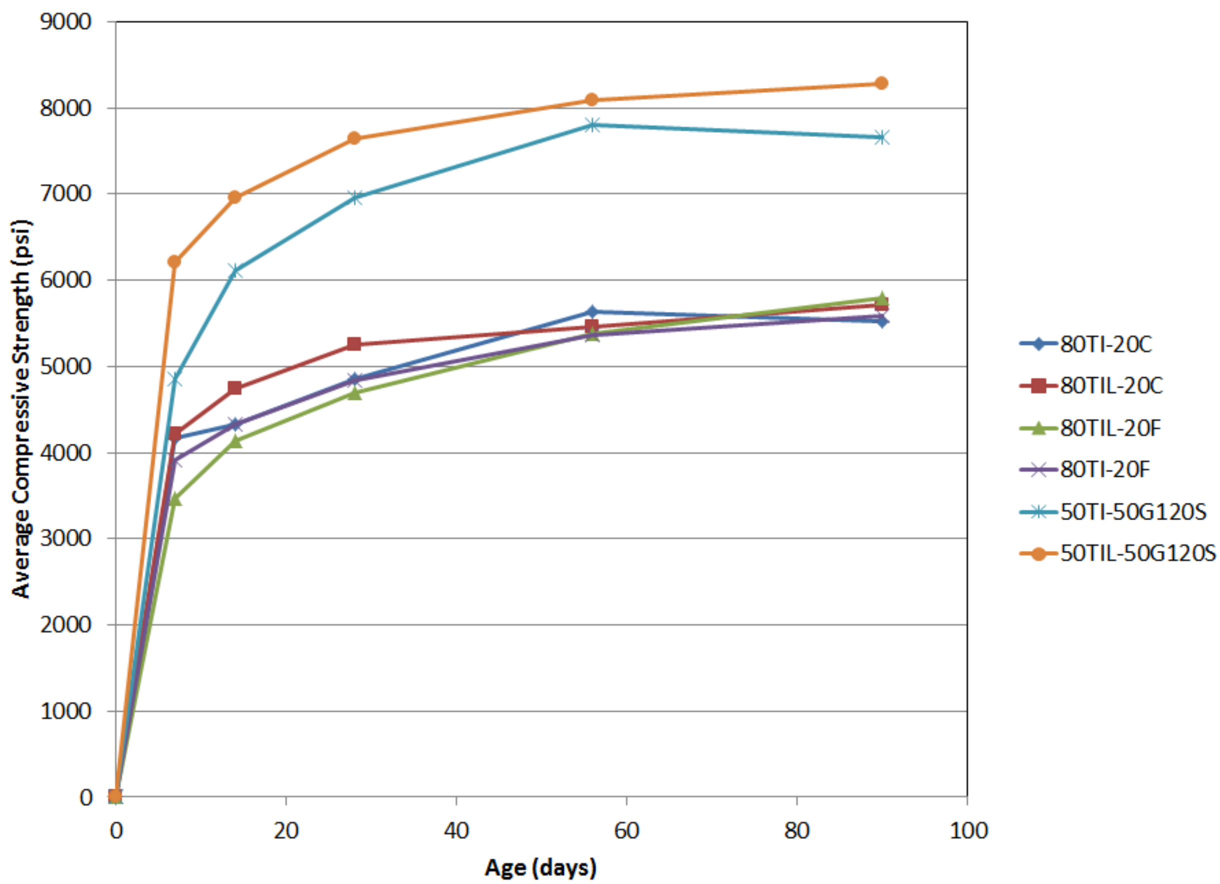

FIGURE 2 Average compressive strength of binary mixtures at 7, 14, 28, 56, and 90 days.

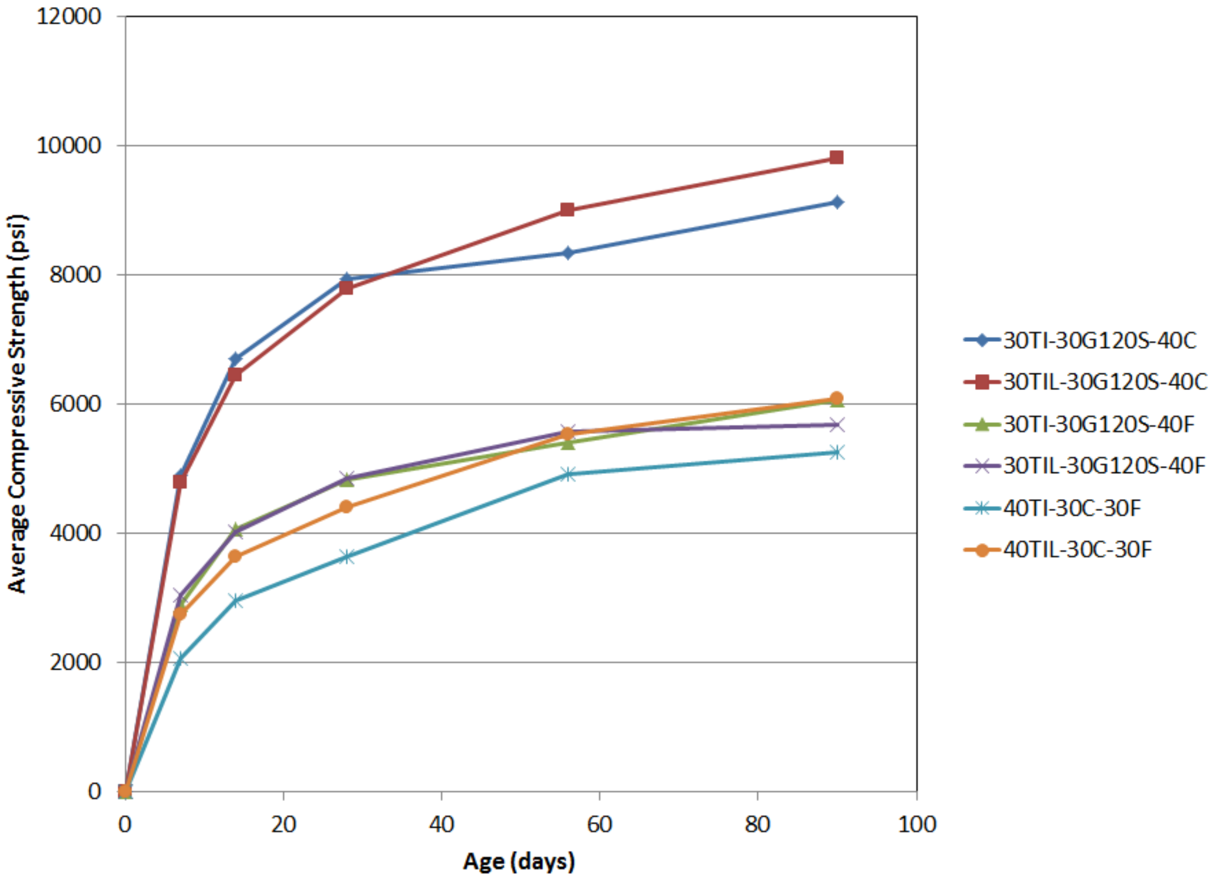

FIGURE 3 Average compressive strength of ternary mixtures at 7, 14, 28, 56, and 90 days.

Figure 4 compares the flexural strength of the mixtures at 28-days of age. Note that the Type IL mixtures are statistically equal at an alpha level of 0.05 for all mixtures except the 50-50 and the 40-30-30 mixtures. The use of the IL cement for the 40-30-30 mixture increased the flexural strength as is expected when looking at the compressive strengths. Although the Type IL flexural strengths were slightly lower on average than the Type I specimens, all were adequate for most paving applications with flexural strengths exceeding 650 psi.

Figure 5 compares the length change between the two sets of mixtures. The results showed that the Type IL samples showed significantly less shrinkage that the Type I samples for all mixtures except the 40-30-30 and the 30-30-40F mixtures, which were statistically equal. This is expected even though the Type IL cement is ground finer due ot the reduced clinker content of the cement of about 10-12 percent. This reduction in clinker reduces the overall shrinkage due to less clinker available to chemically react for chemical shrinkage. This phenomenon can be useful particulary in cases where cracking is not desired such as bridge decks. Reduced shrinkage will equal less cracking leading to a longer service life. This would be further aided by the use of an internal curing agent, which one would need less material to account for chemical shrinkage, due to the lower overal shrinkage.

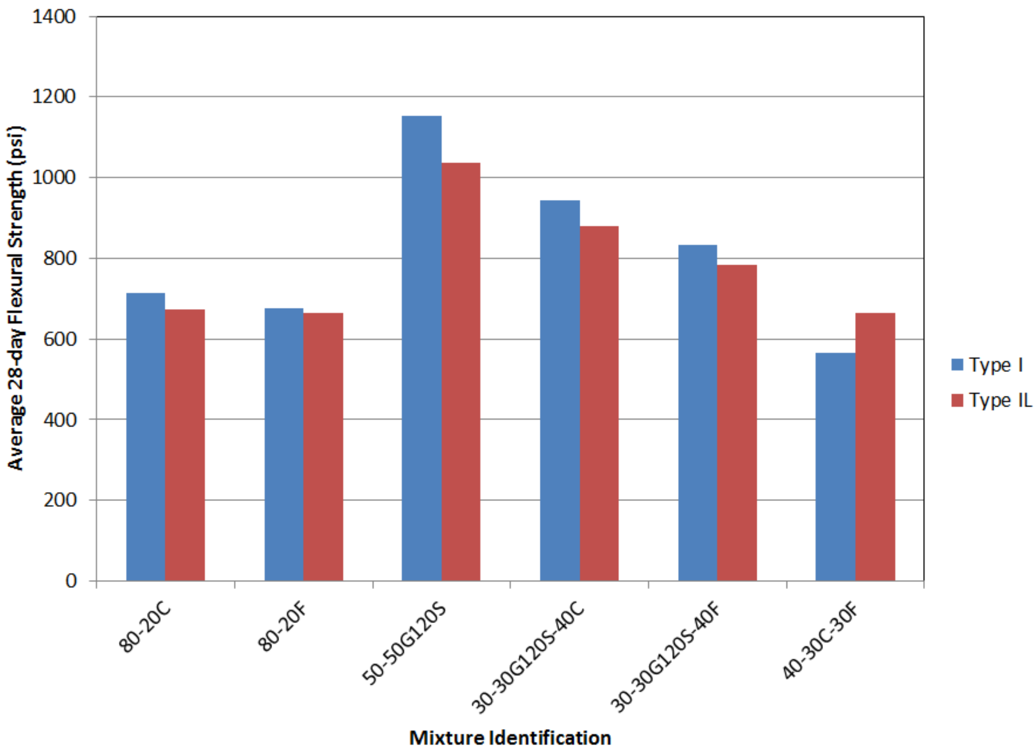

FIGURE 4 Average flexure strength of mixtures at 28-days of age.

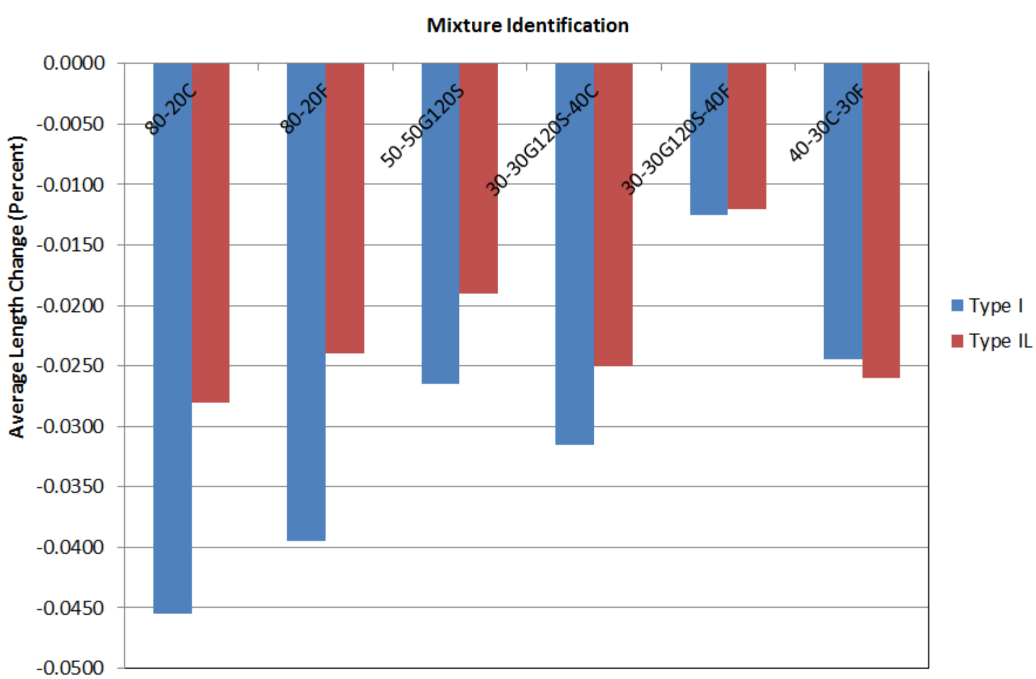

FIGURE 5 Average length change of all mixtures.

Figure 6 shows the surface resistivity for all mixtures. The resuls show no clear trend favoring either the Type I or the Type IL cement except in the 30-30-40C mixture where the Type I outperformed the Type IL significantly. The resistivity results show that the cement type does not significantly affect the outcome of the test because the results are influenced predominately by the degreee of saturation, age, and presence of calcium nitrite.

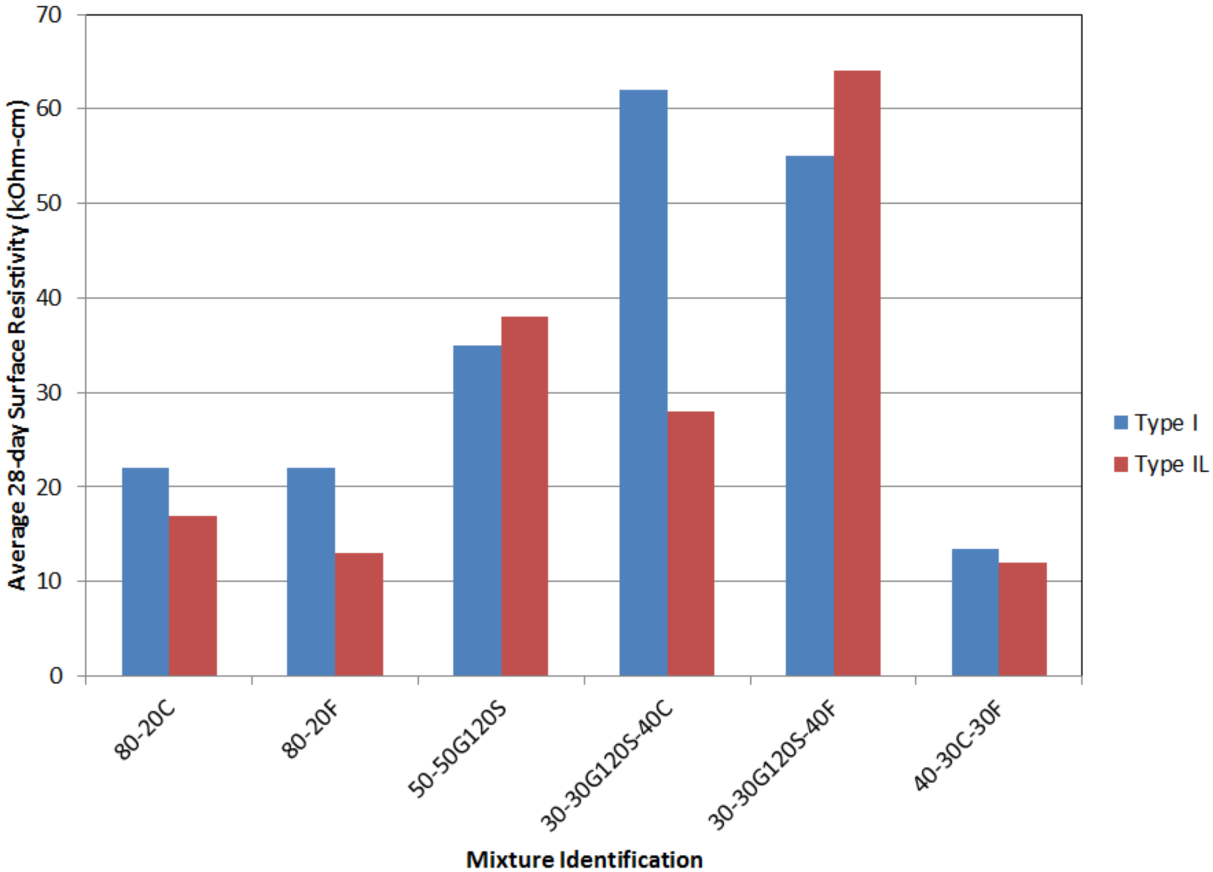

FIGURE 6 Average surface resistivity of all mixtures at 28-days of age.

CONCLUSIONS

The results of this study warrant the following conclusions. Use of Type IL portland cement in Louisiana should be allowed for all applications including ternary mixtures up to 70 percent replacement. Type IL cement tended to reduce the delayed set time for higher volume fly ash mixtures. Compressive and flexural strength results were comparable. Type IL mixtures exhibited less shrinkage when compared to the control mixtures with Type I cement. Surface resistivity results were comparable and indicated that the surface resistivity meter use will be applicable for mixtures containing Type IL cement.

RECOMMENDATIONS

Based upon the results of this study the following recommendations are identified. Allow the use of Type IL portland cement for all structural classes and paving types of concrete use in

Louisiana. Identify locations within the standard specifications that reference Type I or II portland cement use and update to include and allow the use of Type IL portland cement.

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