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Evaluation of Ternary Cementitous Combinations

INTRODUCTION

Portland cement concrete (PCC) is the world's most versatile and utilized construction material. Modern concrete consists of six main ingredients: coarse aggregate, sand, portland cement, supplementary cementitious materials (SCMs), chemical admixtures, and water. Because global demand for PCC sustainability has risen, 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 in 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.

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 the LADOTD specifications. The total replacement rate of cement was varied from 20 to 90 percent.

METHODOLOGY

The cementitious materials for the laboratory portion of this study included: type I/II portland cement, class C and class F fly ash, and grade 100 and grade 120 ground granulated blast furnace slag locally available in the state of Louisiana.

Each of the cementitious materials was chemically characterized according to its respective ASTM standard. Fresh concrete tests included slump, air, unit weight, and set time. Compressive

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strength specimens were cast in triplicate and tested at 7, 28, 56, and 90 days of age. Flexural strength specimens were cast in duplicate 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.

A cost benefit analysis was also completed to compare the current costs associated with construction to those of the new ternary mixtures.

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 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 begins. 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 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.

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 the 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.