MISSOURI S&T

CENTER FOR TRANSPORTATION INFRASTRUCTURE AND SAFETY

HIGH-VOLUME FLY ASH CONCRETE

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16. Abstract

The objective of the proposed study is to design, test, and evaluate high-volume fly ash concrete mixtures. Traditional specifications limit the amount of fly ash to 40% or less cement replacement. This program attempts to increase the ash content to 75% while maintaining strength and durability characteristics. Various mixtures and chemical additives will be tested.

The funding would allow calorimetry studies of potential admixtures and additives necessary to increase the percentage of fly ash in the various concrete mixes. The calorimetry would allow a more diverse and extensive set of variables to be studied, and would assist the researchers in developing mixes specific to each type of fly ash available. The funding would also allow testing for leachability of the HVFA concrete to existing FA concrete and non-FA concrete using TCLP, ASTM 3987, and the new LEAF methods, and to potentially evaluate the various products for radioactivity.

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HIGH-VOLUME FLY ASH CONCRETE

Final Report

To

Ameren Missouri

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BACKGROUND AND OBJECTIVES OF THE STUDY

Since the 1930's, fly ash – a pozzolanic material – has been used as a partial replacement of Portland cement in concrete to improve the material's strength and durability, while also limiting the amount of early heat generation. From an environmental perspective, replacing cement with fly ash reduces concrete's overall carbon footprint and diverts an industrial by-product from the solid waste stream (currently, about 40 percent of fly ash is reclaimed for beneficial reuse and 60 percent is disposed of in landfills).

Traditional specifications limit the amount of fly ash to 35 or 40 percent cement replacement. Recent studies, including those by the investigators, have shown that higher cement replacement percentages – even up to 75 percent – can result in excellent concrete in terms of both strength and durability. Referred to as high-volume fly ash (HVFA) concrete, this material offers a viable alternative to traditional Portland cement concrete and is significantly more sustainable.

However, HVFA concrete is not without its problems. At all replacement rates, fly ash generally slows down the setting time and hardening rates of concrete at early ages, especially under cold weather conditions, and when less reactive fly ashes are used. Furthermore, with industrial by-products, some variability in physical and chemical characteristics will normally occur, not only between power plants but also within the same plant. Consequently, to achieve the benefits of HVFA concrete, guidelines are needed for its proper application in buildings, bridges, roadways, and other transportation-related infrastructure components.

The ***objective*** of the proposed research was to design, test, and evaluate HVFA concrete mixtures. The study focused on the hardened properties of HVFA concrete containing aggregates indigenous to the state of Missouri and fly ash from three of Ameren's power plants – Labadie, Meramec, and Rush Island.

RESEARCH PLAN

The research plan included five (5) tasks necessary to reach the objective. These research tasks consisted of the following:

1. Mix Development
2. Hardened Properties of HVFA Concrete Mixes
3. Bond and Development of Mild Steel
4. Shear and Flexural Strength
5. Conclusions and Recommendations

TASK 1: MIX DEVELOPMENT

The aim of this task was to develop HVFA concrete mix designs that maximized the percentage of fly ash yet still fulfill typical construction needs, such as early strength development. These mix designs served as the basis for the subsequent research. One (1) traditional concrete mix design served as a control during the research. Concrete properties, particularly at higher strengths, are very dependent on aggregate type, so comparison mixes are necessary to allow an unbiased assessment of HVFA concrete mixes containing Missouri aggregates.

TASK 2: HARDENED PROPERTIES OF HVFA CONCRETE MIXES

In this task, the investigators focused on the hardened properties of HVFA concrete as compared to traditional concrete mixes. Broadly speaking, the tests were classified into three (3) main categories: fresh concrete properties (*e.g.*, slump), hardened mechanical properties (*e.g.*, compressive strength, shrinkage), and durability (*e.g.*, freeze-thaw resistance).

TASK 3: BOND AND DEVELOPMENT OF MILD STEEL

The issue to be addressed under this task was to determine whether the current AASHTO LRFD Bridge Design Specifications for development length are appropriate for HVFA concrete. In other words, does HVFA concrete enhance, compromise, or not affect the relationship between development length and compressive strength as previously formulated for conventional Portland cement concrete. Although the design equations are currently valid for fly ash replacement rates up to 35 percent, the micro- and macro-structure of the cementitious system may well change with significantly higher fly ash percentages. Two types of tests were performed: small-scale pull-out tests and full-scale beam splice specimen tests.

TASK 4: SHEAR AND FLEXURAL STRENGTH

This task involved testing of full-scale to demonstrate the potential of HVFA concrete construction. The full-scale specimens included beam specimens for shear and flexural testing. The full-scale specimens were constructed with HVFA concrete from the local Ready Mix Concrete plant to confirm the ability to successfully transfer the mix designs from the laboratory to the field.

TASK 5: CONCLUSIONS AND RECOMMENDATIONS

Based on the results of Tasks 1 through 4, the investigators developed conclusions and recommendations for the use of HVFA concrete.

RESULTS

TASK 1: MIX DEVELOPMENT

The research team successfully developed three HVFA concrete mix designs to compare with a conventional concrete mix design. The mix designs are shown in Table 1. The 70 designation refers to 70% replacement of Portland cement with fly ash, with H representing a relatively high total cementitious content and L representing a relatively low total cementitious content, while the A stands for air-entrained concrete. For the HVFA concrete mixes, the gypsum was used to maintain the initial hydration stage by preventing sulfate depletion, while the calcium hydroxide ensured a more complete hydration of the fly ash with the low content of cement in the mix.

TASK 2: HARDENED PROPERTIES OF HVFA CONCRETE MIXES

Results of the mechanical property tests indicated that the HVFA concrete mixes were comparable to conventional concrete. With regard to the durability tests, the HVFA concrete showed improved resistance to chloride penetration, improved freeze-thaw durability, but poor scaling resistance.

Table 1: Concrete Mix Designs per Cubic Yard

Component	Mix Design ID			
	Control	HVFA-70H	HVFA-70L	HVFA-70LA
Cement (Type I) (lb)	564	219	155	155
Fly Ash (lb)	0	511	360	360
w/cm	0.40	0.40	0.40	0.40
Coarse Aggregate (lb)	1860	1754	1860	1860
Fine Aggregate (lb)	1240	1080	1240	1240
HRWR (fl. oz)	16.9	21.9	15.45	15.45
Air Entrainment (fl. oz)	3.5	0	0	3.2
CaOH (lb)	0	51	39	39
Gypsum (lb)	0	21	16	16

Task 3: Bond and Development of Mild Steel

Results of the small-scale pull-out specimens indicated that the average peak load for the #4, HVFA-70H and HVFA-70L pull-out specimens was 0.7% lower and 2.3% higher than that of the control, respectively. The average peak load for the #6, HVFA-70H and HVFA-70L pull-out specimens was 12% and 9.2% higher than that of the control, respectively. This data indicates that both HVFA mix designs have comparable bond strengths to the control mix design with #4 reinforcing bars and higher bond strength with #6 reinforcing bars. However, statistical analysis indicates that all three mix designs performed equally.

Results of the full-scale beam splice specimens indicated that the average peak bar stress for the HVFA-70H and HVFA-70L bottom splice beam specimens was 29% and 15% higher than that of the control specimens, respectively. The peak bar stress for the HVFA-70H and HVFA-70L top splice beam specimens was 49% and 23% higher than that of the control specimens, respectively. This data indicates that both HVFA mix designs exhibited improved bond performance under realistic stress states than the control mix design.

Task 4: Shear and Flexural Strength

Results of the full-scale shear and flexural strength tests indicated that the HVFA concrete mixes were comparable to conventional concrete and that existing design standards are applicable to HVFA concrete. Figure 1 shows a comparison between the conventional concrete and HVFA concrete shear tests (note the similarity in morphology of the critical shear crack).

CONCLUSIONS

Based on the results of the research program, HVFA concrete offers a viable alternative to traditional concrete mixes. HVFA concrete has comparable mechanical properties, improved durability properties, and comparable structural behavior. The only negative aspect of the HVFA concrete involved scaling resistance. Based on the favorable results of this investigation, the Missouri Department of Transportation has agreed to construct a prototype bridge incorporating HVFA concrete. Construction is scheduled to begin September 1, 2012.

(a) Conventional Concrete

(b) HVFA Concrete

Figure 1: Full-Scale Shear Specimen Tests