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BOTTOM ASH AS AGGREGATE REPLACEMENT IN CONCRETE

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16. Abstract
The objective of the proposed study is to evaluate bottom ash as a partial or total replacement of the fine and coarse aggregate in concrete. This program will characterize and evaluate available bottom ash sources as potential replacement of both the fine (sand) and coarse (stone) natural aggregates traditionally used in the construction of bridges, roadways, culverts, retaining walls, and other transportation-related infrastructure components.

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BOTTOM ASH AS AGGREGATE REPLACEMENT IN CONCRETE

Final Report

To

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BACKGROUND AND OBJECTIVES OF THE STUDY

Although relatively unreactive compared to fly ash, bottom ash does have the potential to replace either all or a portion of the natural aggregates used in concrete. In particular, bottom ash holds considerable potential for use as internal curing of high-performance concretes. High-performance concretes have resulted in more durable transportation structures, reducing life-cycle costs and increasing sustainability of the nation's transportation network. Internal curing can aid in producing even higher performing concretes with increased resistance to early-age cracking as well as enhanced durability. The result is a more durable transportation system and thus improved performance, longer life, and lower costs. Furthermore, the use of bottom ash to provide the internal curing will turn a waste product into a viable construction material, removing it from the solid waste stream.

High-performance concretes offer the potential for smaller element cross-sections and increased durability, reducing both first and life-cycle costs. However, to extend the benefits of high-performance concretes, internal curing is required to reduce the potential for early-age cracking and develop the full strength potential of the material. Bottom ash – a waste product from the burning of coal – can provide one method of internal curing. Why the need for internal curing over traditional external curing methods such as fogging, misting, and wet burlap? Basically, the capillary porosity of higher performing concretes becomes disconnected during the first few days of hydration, such that external water may only penetrate less than one-tenth of an inch. Without internal sources of water, the concrete can self-desiccate, which results in significant internal stresses and unhydrated (wasted) cement. The purpose of internal curing is to provide water as needed throughout the interior of the concrete element, resulting in complete cement hydration and the elimination of autogenous stresses that can lead to early-age cracking.

Another potential application of bottom ash is for internal curing of high-volume fly ash (HVFA) concrete – concrete with at least 50% of the Portland cement replaced with fly ash. Traditional specifications limit the amount of fly ash to 35 or 40% cement replacement. Recent studies, including those by the investigators, have shown that higher cement replacement percentages – even up to 75% – can result in excellent concrete in terms of both strength and durability. However, although initial autogenous shrinkage is reduced in HVFA concrete mixes, they are more prone to higher rates of shrinkage and cracking at later ages (after seven days). This phenomenon is related to pore size distribution as well as continued effects of hydration and the pozzolanic reaction. The use of prewetted bottom ash as internal curing can reduce this propensity for later age autogeneous shrinkage and cracking.

Bottom ash is a waste product from the burning of coal in thermal power plants. Most modern plants pulverize the coal before it is injected into the boiler. The non-combustible material remaining after burning becomes either fly ash or bottom ash. Bottom ash results when the non-combustible material agglomerates in cooler sections of the boiler and eventually falls to the bottom, as opposed to fly ash, which travels upward with the combustion gases. Bottom ash is primarily comprised of fused coarser ash particles. Frequently, these particles are very porous and resemble volcanic lava. In essence, the porous nature of the bottom ash allows it to act as a brittle sponge, which will store water and release it over time to provide the internal curing. In terms of current uses, if the bottom ash meets certain requirements, it can be used as lightweight aggregate in concrete blocks. However, a considerable amount of bottom ash is still disposed of in landfills. There is a significant potential to use a waste product to improve both high-performance concretes and HVFA concretes.

The ***objective*** of the study was to evaluate the use of bottom ash for internal curing of both high-performance concrete and HVFA concrete. Both types of specialty concretes have the potential to self-desiccate – a process in which the material cannot maintain 100 percent relative humidity during curing, resulting in only partial curing, early-age cracking, and decreased durability.

RESEARCH PLAN

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

1. Mortar Mix Development
2. Mortar Mix Shrinkage Study
3. Concrete Mix Development
4. Concrete Mix Shrinkage Study
5. Conclusions and Recommendations

TASK 1: MORTAR MIX DEVELOPMENT

The aim of this task was to develop a high-performance mortar mix and a HVFA mortar mix to form the basis of the initial phase of the internal curing study.

TASK 2: MORTAR MIX SHRINKAGE STUDY

In this task, the investigators studied the shrinkage of the mortar mixes developed in Task 1. The comparison examined each mix with and without prewetted bottom ash of a size normally referred to as manufactured sand. Chemical shrinkage was measured in accordance with ASTM C1608-07, “Standard Test Method for Chemical Shrinkage of Hydraulic Cement Paste,” while linear autogenous shrinkage was measured in accordance with ASTM C1698-09, “Standard Test method for Autogenous Strain of Cement Paste and Mortar.” Restrained shrinkage cracking was measured in accordance with ASTM C1581-09, “Standard Test Method for Determining Age at Cracking and Induced Tensile Stress Characteristics of Mortar and Concrete under Restrained Shrinkage.”

TASK 3: CONCRETE MIX DEVELOPMENT

The aim of this task was to develop a high-performance concrete mix and a HVFA concrete mix to form the basis of the second phase of the internal curing study.

TASK 4: CONCRETE MIX SHRINKAGE STUDY

In this task, the investigators studied the shrinkage of the concrete mixes developed in Task 3. The comparison examined each mix with and without prewetted bottom ash in the form of both manufactured sand and small coarse aggregate. The shrinkage was measured in accordance with ASTM C157-08, “Standard Test Method for Length Change of Hardened Hydraulic-Cement Mortar and Concrete. The only modification made to the ASTM specification was to use a cylindrical specimen with a 4 in. diameter and 24 in. length.

TASK 5: CONCLUSIONS AND RECOMMENDATIONS

Based on the results of Tasks 1 through 4, the investigators developed conclusions and recommendations for the use of bottom ash for internal curing.

RESULTS

TASK 1: MORTAR MIX DEVELOPMENT

Four mortar mixes were developed for the initial phase of the study. The high-performance mortar mixes used a 0.30 *w/c*, Type I Portland cement, and a 3:1 sand/cement ratio. The HVFA mortar mixes used a 0.30 *w/c*, Type I Portland cement, Class C fly ash, 60% replacement of cement with fly ash, and a 3:1 sand/cement ratio. The control mixes used natural sand, while the internal curing specimens used bottom ash manufactured sand.

TASK 2: MORTAR MIX SHRINKAGE STUDY

Results of the mortar mix shrinkage study indicated that the mixes containing prewetted bottom ash experienced early-age shrinkage comparable to the identical mixes without prewetted bottom ash. However, long-term shrinkage was significantly reduced for the mixes containing bottom ash, on the order of 50%. Furthermore, restrained shrinkage tests indicated reduced restraint stresses for the mortars containing prewetted bottom ash as well as a significant delay in the onset of shrinkage cracking.

TASK 3: CONCRETE MIX DEVELOPMENT

The concrete mixes were developed by adding coarse aggregate to the mortar mixes used in Task 1. For the control mixes, the coarse aggregate consisted of crushed limestone with a maximum nominal aggregate size of 3/8-in. For the internal curing mixes, the limestone was replaced with bottom ash with a maximum nominal size of 3/8-in.

TASK 4: CONCRETE MIX SHRINKAGE STUDY

Results of the concrete mix shrinkage study indicated that the mixes containing prewetted fine and coarse aggregate experienced decreased shrinkage throughout the testing period. The internally cured high-performance concrete experienced an average shrinkage of 440 micro-strain, while the control shrinkage averaged 560 micro-strain. The difference for the HVFA concrete mixes was even more pronounced, with the internally cured specimens averaging a shrinkage of 385 micro-strain, while the control shrinkage averaged 605 micro-strain. Figure 1 shows the shrinkage specimens.

CONCLUSIONS

Based on the results of the research program, bottom ash offers a viable method of providing internal curing for both high-performance concretes and HVFA concretes. The prewetted fine and coarse aggregate bottom ash significantly reduced the overall shrinkage and restraint strains compared to the control mixes. The next phase of research should involve a study of the mechanical properties of concretes containing bottom ash.

Figure 1: Shrinkage Specimens with DEMEC Strain Measurement Points