ISSUE 1 • 2009

ASH at work

Applications, Science and Sustainability of Coal Ash

A GREEN GEM IN THE TREASURE STATE

PROJECT USES CONCRETE MIX WITH 100 PERCENT FLY ASH

GEOPOLYMER CONCRETES

A GREEN CONSTRUCTION TECHNOLOGY RISING FROM THE ASH

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The Arthur Ravenel Jr. Bridge, Charleston, South Carolina, was constructed using high-volume fly ash concrete.

A GREEN GEM *in the* TREASURE STATE

Project Uses Concrete Mix with 100 Percent Fly Ash

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ABOVE PHOTO:
Ground and polished floor slab before sealing

PROJECT AND PARTICIPANTS

In 2007, MacArthur, Means and Wells (MMW) Architects of Missoula, Mont., contacted researchers at the Western Transportation Institute (WTI) at Montana State University (MSU) about using innovative concrete materials in an effort to achieve a Platinum (highest rating possible) LEED certification on a commercial building project they were working on for the Missoula Federal Credit Union (MFCU). Part of a project's rating is based on the characteristics of the materials from which it is constructed, with points being awarded for the use of recycled and locally available materials. MMW was interested in using a concrete that was produced with locally available fly ash for the binder and pulverized container glass for the aggregate. Ultimately, the footings and foundation walls, floor slabs, exterior precast architectural wall panels, and two interior load-bearing beams were constructed with this new, environmentally friendly material.

Prior to the MMW project, significant research had been conducted at Montana State University (MSU) on structural concretes in which 100 percent of the portland cement was replaced with fly ash.[1,2] In working with this new material, it was quickly discovered that it offered exceptional performance with respect to short-term strength gain, long-term ultimate strength, and workability relative to traditional portland cement concrete. Concrete mixtures with 100 percent fly ash routinely achieve two-day strengths in excess of 2,900 psi and 28-day strengths in excess of 4,800 psi (without extraordinary curing measures). Subsequent long-term strengths have reached as high as 8,000 psi at one year of age. These results have been achieved with very workable mixtures (6-inch slump) without the use of sophisticated admixtures common in the concrete industry.

In 2000, researchers at WTI/MSU began informally investigating the use of pulverized glass in 100 percent fly ash concrete for nonstructural applications, such as countertops and other architectual surfaces. The concrete mixes resulting from this work showed promise for structural applications with similar set times, workability, and strengths of traditional concrete. However, before moving ahead with this material in any such applications, it was recognized that significant testing would be required to investigate its fundamental engineering properties and long term durability, and the applicability of existing structural engineering design procedures in its use. This MMW project gave WTI/MSU the opportunity to formally begin researching these matters for 100 percent fly ash concrete made with glass aggregate.

Because of scheduling constraints, the research effort was focused only on the specific needs of this project, which consisted primarily of determining the specific mixture proportions required to produce a fly ash, glass aggregate concrete that met the performance requirements of the project, and subsequently confirming its durability and behavior in reinforced structural elements. Briefly described below are the steps that were taken to make this "green concrete" work for this project in Missoula.

MIX DESIGN AND MATERIALS

The fly ash used for this project is a Class C fly ash from the Corette Power Plant in Billings, Mont. Selected characteristics of this fly ash are presented in Table 1. Note the high calcium content, which is critical to the hydration reaction that occurs when water is added to the fly ash.

TABLE 1 Fly Ash Properties

Chemical						Physical		
Silicon Dioxide (%)	Aluminum Oxide (%)	Iron Oxide (%)	Sulfur Trioxide (%)	Calcium Oxide (%)	Loss on Ignition (%)	Fineness, Retained on #325 Sieve (%)	Soundness, Autoclave Expansion (%)	Density
32.37	17.52	5.34	2.02	28.89	0.23	12.1	0.17	2.72

The recycled pulverized glass was of mixed color and was provided by the Montana Department of Environmental Quality. It was pulverized using an Andela crusher operated by Headwaters Recycling based in Helena, Mont. The glass particles were separated into two distinct size fractions, 1/8 inch minus and 3/8 inch to 1/8 inch. To ensure uniformity with respect to set time and strength gain, all the pulverized glass was thoroughly washed prior to use in the concrete mixtures.

One impediment to using 100 percent high calcium fly ash is the accelerated rate at which chemical reactions begin to occur when water is added, which leads to flash setting of the material. To avoid flash setting, 20 Mule Team Borax ($Na_2B_2O_3 \cdot 10H_2O$) was used as a set retarding admixture.

Two mix designs were developed for this project (Table 2). Both mixtures had a water-to-fly ash ratio (w/fa) of 0.20. The mixtures differed only in the aggregate size; one mix, referred to as mix (c), used equal amounts of fine (1/8 inch minus) and coarse (3/8 to 1/8 inch) glass, while a second mix, referred to as mix (f), only used the fine glass (1/8 inch minus).

TABLE 2 Mix Designs for 1 yd3

Batch	Water (lb)	Fly Ash (lb)	Fine Glass (lb)	Course Glass (lb)	Borax (lb)
c	346.68	1733.67	792.45	792.45	21.60
f	348.57	1742.58	1573.83	0	21.78

The criteria for developing the two mix designs were based on workability (slump of six to eight inches), set time (two to four hours), strength gain (greater than 4,000 psi at 28 days) and dimensional stability (nominal shrinkage). Once the mix designs were completed in the laboratory, full size trial mixtures were batched and mixed at the concrete producer's yard. Trial mixtures are paramount to successfully implementing this new material because they give key personnel an opportunity to observe firsthand its workability and setting behavior prior to actual application on the construction site. Once the trial pours were successfully completed, work began on the MFCU building, itself.

Chapman Concrete Construction Inc. employees hand-broadcasting green glass on surface of slab. (May 2008)

Chapman Concrete Construction Inc. employees placing interior slab sections. (May 2008)

DURABILITY

A major cause of deterioration of concrete is the generation of expansive forces within the material, which can result from delayed chemical reactions between alkali in the binder and silica in the aggregates (referred to as akali-silica reactivity or ASR), and/or physical expansion of water within the material during repeated freeze-thaw cycles.

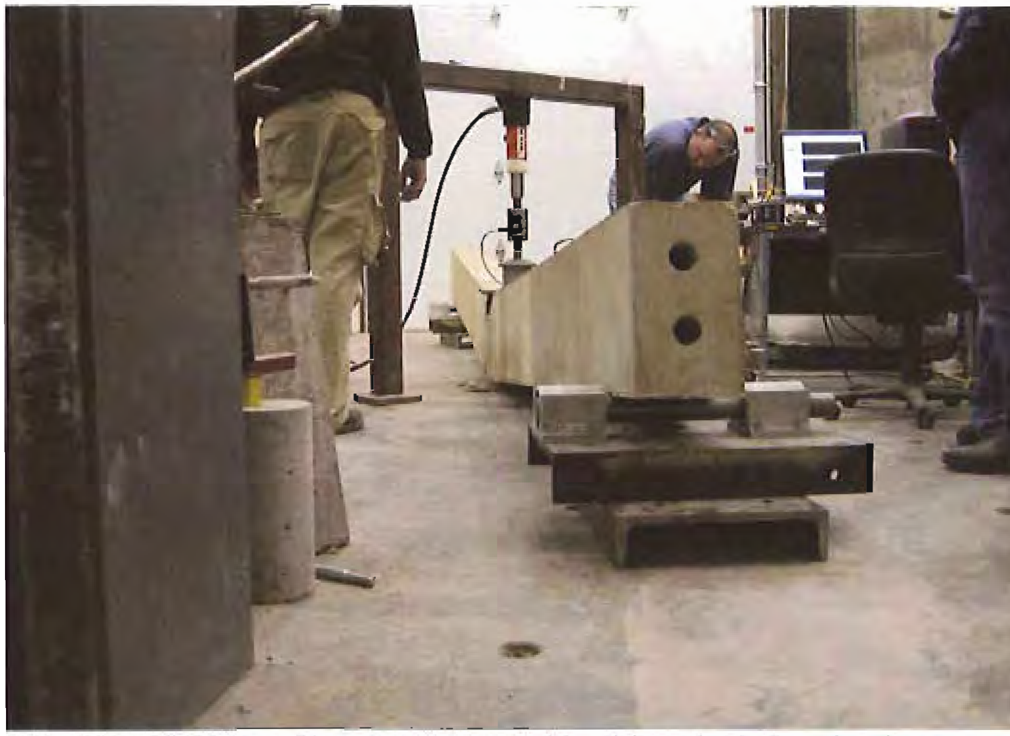
The susceptibility of a particular concrete to ASR-related degradation is difficult to predict based simply on the properties of the binder and the aggregates themselves. Thus, this susceptibility is generally determined by testing. There are several accelerated test methods for determining ASR reactivity in concrete; ASTM C1260 was deemed to be the most appropriate test method for this project. In this test, mortar bars are submerged in a heated alkali solution, and their expansion is measured over time. The recommended limit of expansion to delineate potentially reactive aggregates is 0.2 percent (ASTM C1260) over 14 days, although some agencies adopt a more conservative limit of 0.10 percent. For this project, mix (f) had an average expansion at 14 days of 0.0312 percent and a 28-day expansion of 0.0597 percent; both of these values are well below the limits mentioned above. Mix (c) also performed well with 0.050 and 0.146 percent expansion at 14 and 29 days respectively.

Freeze-thaw resistance is being quantified following the procedures in ASTM C666 (Procedure A). This test method consists of subjecting concrete specimens to multiple freeze-thaw cycles while fully saturated. Weight loss and change in dynamic modulus are being monitored as a function of accumulated freeze-thaw cycles. As may be obvious, the degree of damage sustained by the concrete due to micro (as well as macro) cracking under freeze-thaw action is reflected by its attendant loss of weight and stiffness, where material stiffness can be non-destructively measured in terms of dynamic modulus. Once 300 cycles are completed, a durability factor will be calculated for the particular mix designs being investigated.

MMW's project for the MFCU has been an excellent next step and afforded WTI/MSU an excellent opportunity to continue its research and development of 100 percent fly ash concrete for building applications.

STRUCTURAL

In almost all structural applications, concrete must be reinforced to provide the strength and/or ductility required in contemporary designs. While the behavior of conventional concrete coupled with reinforcing steel is well understood, this behavior is complex, and it is important to confirm by laboratory test how reinforced elements behave that are made with new materials, such as fly ash as the binder and recycled glass as the aggregate. Past work at MSU has consistently confirmed that structural elements made with fly ash concrete with conventional aggregate behave similar to elements made with traditional portland cement concrete.[2]



Half scale beam test at failure. (November 2007) Kyle Applebury is inspecting the flexural cracks.

The structural performance of 100 percent fly ash concrete with recycled pulverized glass aggregate was investigated through a series of 12 beam tests. The beams were tested in third-point bending until failure, and the force-deflection behavior was monitored. One of the 12 beams was a half-scale model of the actual beams used in the MFCU building.

The results of these beam tests indicated that using existing design equations to determine the capacity and performance of reinforced elements made with this material appears promising. The predicted moment capacities of all the beams were within 12 percent of their actual capacities.

With respect to shear, the actual capacity exceeded the calculated capacity in all cases, although some of this apparent conservativism may be related to the test configuration used, rather than being an inherent property of the material (additional testing is necessary and is planned in this regard).


Actual precast load bearing beams. (June 2008)

CONCLUDING REMARKS

MMW's project for the MFCU has been an excellent next step and afforded WTI/MSU an excellent opportunity to continue its research and development of 100 percent fly ash concrete for building applications. Building on previous projects which included casting ecological blocks, a building foundation, cast in place slabs, and many precast vault toilets for the Forest service, the results from this research program have proven that this is a viable building product and that in some respects it outperforms portland cement concrete.

While many people have contributed to the success of this project, the owners (MFCU), the architects (MMW) and the consulting engineers (Beaudette Consulting Engineers Inc.) of Missoula, Mont. need to be recognized for their ongoing commitment to push smart sustainable building to new heights. ❖

MacArthur, Means and Wells (MMW) Architects achieved a Platinum LEED certification for this commercial building project they were working on for the Missoula Federal Credit Union (MFCU).

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