CCP Grouts: Stomach Lining for Sick Mines

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Each day, in the shadow of Maryland’s highest point, the Kempton Mine Complex belches forth 3.5 million gallons of acid (pH 3.0) mine water. Now comes the Maryland Power Plant Research Program (MPPRP) with a bold proposal to use local coal combustion products (CCPs) to prevent the air, water, and pyrites from getting together to produce their bile—all part of the MPPRP’s aggressive program to fully utilize the CCPs produced within the state.

Power plants in Maryland currently produce about 1.5 million tons per year of CCPs, and growth to 2 million tons per year is expected. Currently, only about 30 percent of these CCPs are used beneficially; the remaining 70 percent being landfilled. The landfilling of CCPs consumes valuable land and has the potential to adversely affect Maryland’s aquatic resources.

In 1995, the MPPRP and the Maryland Department of the Environment Bureau of Mines established the Western Maryland Coal Combustion Products/Acid Mine Drainage Initiative. The initiative, which is jointly funded by public and private sectors, spearheads Maryland’s research and development of beneficial large-volume uses of CCPs to reduce acid formation in Maryland’s abandoned underground coal mines. The initiative emphasizes the prevention of acid formation rather than treatment of acid mine waters.

In 1996, the initiative’s first project, the Winding Ridge Project, injected 5,600 cubic yards of a 100 percent CCP-based grout into an underground coal mine, and successfully reduced acid formation in that mine by as much as 90 percent. The Siege of Acre Project is one of several projects underway or planned by the MPPRP to use CCP-based grouts to reduce acid formation.

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reduce acid formation in Maryland’s 450 abandoned coal mines.

In general, the MPPRP’s strategy is to demonstrate that grouts made of CCPs can be used as a replacement for ordinary cement mixtures in most geotechnical engineering applications. Mine restoration has focused on acid mine drainage (AMD) but will eventually address subsidence and disruption of water patterns in watersheds disturbed by underground mining.

Objectives

The Siege of Acre Project is a field-scale experiment designed to evaluate the impact on acid production of covering pyritic mine pavement and high sulfur mine debris left in abandoned mines. The impermeable covering proposed is a hydraulically-placed fluid grout composed of mine water and locally available CCPs.

The Kempton Mine Complex covers about 12 square miles in Maryland and West Virginia, and discharges AMD at a rate of approximately 3.5 million gallons per day into Laurel Run, the first major tributary to the North Branch of the Potomac River. The Siege of Acre segment of the Kempton Complex forms the northern extremity of the mine workings in Maryland (refer to the map on page 1). In particular, it includes an isolated straight run of three tunnels, each 750 feet long by 16 feet wide, running up dip from the northern edge of the Kempton mine pool, and subaerial pavement in other Upper Freeport mines in Maryland and neighboring states.

Project Tasks

The Siege of Acre Project is planned in be completed in two phases for an important technical reason: if there is no reliable flow of low pH water off the pavement in this segment of the mine the experiment could not be conducted. Thus, phase I was planned to determine the exact location and orientation of the mine tunnels and provide access to monitor water (if any was found) coming off the pavement in this segment of the mine.

Phase I of the project was completed during 2001 and 2002 with the help of Department of Energy funds provided under a subcontract with West Virginia University, contract agent for the Combustion Byproducts Recycling Consortium (CBRC). The three tasks of phase I included careful mapping and drilling to find the mine tunnels under 140 to 175 feet of overburden, determining their exact orientation, preparations for baseline water quality monitoring, and preliminary design of the grout using locally produced combustion products.

The investigation to determine the exact location and orientation of the mine was a challenge worthy of extensive discussion, especially in view of the recent accident at the Quecreek Mine in Pennsylvania, which was associated with interpreting an old mine map. The initial drilling locations to find the Siege of Acre tunnels were identified by a rigorous review of the 50-year-old historical mine map. This map was known to have been prepared over a 30-year period of progressively mining north from Davis, West Virginia, and then jumping ahead to Kempton, Maryland, in 1912.

From the 420-foot shafts in Kempton, the mine continued its northward march two miles to the Siege of Acre segment until closed in 1950. The closest reference points to the Siege of Acre tunnels identified on both the mine map and the surface are an airshaft and a power borehole 4,000 feet from the experimental site. It also was known that the best of mine mapping in this period employed rather crude survey methods compared to modern lasers and global positioning systems and were subject to changing magnetic declinations.

After extensive field reconnaissance and careful surveying of suspected subsidence depressions, it was estimated that distances on the mine map had to be foreshortened by a factor of .00875 (35 feet over the 4,000 feet to the closest reference points), but it was impossible to estimate the degree of rotation needed to precisely place the Siege of Acre segment of the mine relative to the surface. Drilling at a location determined to have the highest probability of hitting a tunnel resulted in hitting the tunnel below the surface of the mine pool. This hole has been retained for sampling the mine pool in the area, initially the depth of water in it provided a reference point for drilling a second hole into the tunnel above mine pool.

Downhole camera observations in the second and subsequent holes guided additional drilling until the
exact geometry of all three tunnels was established. At the time of initial drilling in November 2001, no water was observed coming off the pavement at the proposed site for the experiment. Since the area had endured an unusual drought over the summer, it was decided to observe the tunnels for several months to determine if the initial observation was an anomaly.

Camera observations since December 2001 have shown water flowing under the hole drilled into the southwest tunnel so the experiment can proceed. Baseline water quality monitoring is underway at the site.

**Grout Mix Design**

The laboratory investigation conducted by Hemmings & Associates using locally available CCPs focused on the specifics of the mine geometry and conditions observed by the downhole cameras. The CCP materials selected for the grouts were fluidized bed combustion (FBC) ash and pulverized coal fly ash (PFA) from the North Branch and Mount Storm power plants, respectively, both located close to the Kempton Mine Complex.

A grout formulation has been developed using these materials to provide a competent fluid grout that will spread and flow long distances through the debris on the mine floor where slopes vary from 15 to 19 percent. The ability to design a grout with an angle of repose comparable to the slope of the mine floor is crucial to economy in drilling injection holes and, at the same time, not have the grout flow away into the mine pool.

Because of the complexity of the abandoned mine workings and debris, the CCP-based grouts are being designed to be adaptable to a variety of anticipated conditions underground with the following generalized performance criteria:

- rheological properties to provide sufficient fluidity to ensure good pumpability,
- optimum fissure and/or mine debris penetration and lateral transport underground,
- adequate durability to withstand possible low-pH water flowing on it for long periods of time, and
- in-situ characteristics to prevent acid formation or leaching of heavy metals in the abandoned mine workings.

The all important consideration is that the CCP grouts should be stable and compatible with the mine water present on the mine floor. This is particularly important with respect to the ability of the grout to retain its chemical integrity against potential dissolution and release of metals into either groundwater or surface water.

Rheologically, the PFA-FBC grouts exhibit good fluidity, with stable Bingham flow and cohesiveness in the solids content (Cw) range Cw = 65 to 71 percent. Above this range, the grouts quickly start to exhibit pseudoplastic flow with reduced fluidity as a consequence of rapidly increasing yield stress, plastic viscosity, and thixotropy.

Below Cw = 65 percent, there is a tendency towards solid-liquid separation, which could lead to problems during pumping and placement. Because of the higher fines content of the PFA compared to the FBC material, grouts with a higher proportion of PFA tend to be more cohesive at a given Cw, with slightly higher yield stress and plastic viscosity.

Physically, compressive strengths for the grouts can be targeted in the range 100 pounds per square inch (psi) to over 2,000 psi to meet the needs of widely different exposure conditions underground. While compressive strength is not an important consideration in the conventional sense for this application, it is considered to be an important surrogate for durability. The grouts are surprisingly well-behaved from a design perspective, with strength potential being controlled predictably by the water to FBC (w/fbc) ratio—exactly analogous to the water to solids content (w/c) ratio controlling strength in concrete technology.

To a first approximation, the FBC material, therefore, plays the role of the primary cement for the system. It is evident that, with the possible exception of bulk filling of dry areas near the upper ends of the tunnels, the grouts will need to contain at least 25 wt percent of the FBC material (on a dry basis) to achieve adequate durability (in-situ strength).

Mechanistically, the development of strength in the grouts is the result of a complex sequence of sulfopozzolanic and silico-pozzolanic reactions involving the residual lime alkalinity, anhydrite and amorphous dehydroxylated clays/shales present in the FBC material, and the aluminosilicate glass in the PFA. The significant product from these reactions is the calcium sulfoaluminate ettringite, which has good cementitious properties and, therefore,
Coal remains the major fuel burned for power production in the U.S. In 1998, power production from coal generated nearly 45 million tons of fly ash and over 10 million tons of bottom ash as part of the coal combustion byproduct waste stream. This material is composed of noncrystalline oxides of silicon (SiO$_2$), aluminum (Al$_2$O$_3$), iron (Fe$_2$O$_3$), calcium (CaO), and minor quantities of other metal oxides (i.e., magnesium, sodium, titanium, and potassium).

The precise composition of fly and bottom ash varies depending on the source of the coal being burned. The physical properties of the ash vary with the type and uniformity of the coal, the operating parameters of the power plant, and the collection methods employed to separate the ash from the combustion stream. Although some portion of this ash is used in beneficial applications, primarily in the construction industry, significant portions are disposed of in landfills.

**Fly Ash Can Benefit Foundry Industry, Workers**

The foundry industry in the U.S. comprises approximately 3,000 independent companies found in all 50 states. While 85 percent of these companies are small businesses employing fewer than 100 people, the industry as a whole provides well-paying jobs for over 200,000 people each year.

With the exception of die casting, sand molds and cores are used in nearly every casting process practiced in the U.S. with foundries using about 100 million tons of sand per year in their operations. Only the largest foundries generate the amounts needed to justify the capital equipment necessary to reuse this sand in foundry applications or to process the sand into a relatively clean material for use in construction applications. Every year, 8 to 10 million cubic yards of this sand are placed in landfills at a yearly cost of 100 to 250 million dollars.

Aside from the disposal costs associated with casting sands, the biggest concern surrounding its use in the foundry industry is employee exposure to crystalline silica. Common foundry sands are composed of crystalline silica (quartz) materials. As such, prolonged exposure to dusts form these sands can cause silicosis. This is particularly true when very fine grades of sand are handled.

The Occupational Safety and Health Agency (OSHA) has proposed lowering the allowable workplace exposure of crystalline silica by 50 percent to 0.05 mg/m$^3$. This level of exposure might be difficult to achieve at many foundries. In addition, the record keeping, reporting, training, and medical surveillance required under the new standards would be extremely time consuming and costly.

**Fly Ash Can Replace Foundry Sand**

High silica sand is an extremely good material for casting molds because it has the ability to withstand the temperature of the molten metal, can absorb and transmit heat, and has sufficient permeability to allow gasses generated during casting to pass between the particles without causing casting defects. Fly ash and bottom ash have many of the
same attributes. These materials have a very high melting point, can absorb and transmit heat during pouring, and have the ability to allow gases to pass through a compacted mass.

Foundry sands are processed within strict particle size distributions to tailor the properties of the material to the intended casting process. The major difficulty with fly or bottom ash is the fact that it currently is generated in a manner that is optimized for coal combustion. The particle size distribution that results is determined by combustion criteria without any thought for the properties required to use the resultant ash in any secondary application.

However, it was found that it is possible to determine and modify the particle size distribution of fly ash or bottom ash in such a manner that the resulting material could be acceptable as a replacement for foundry sand in some applications. This project determined that fly ash could act as a replacement for foundry sand and has been justified in a number of ways.

**Fly Ash Advantages**

First, the use of fly ash would eliminate a portion of the total amount of material being sent to landfills. Granted the fly ash or bottom ash so used would be landfilled in the same manner as the foundry sand currently in use. However, since the ash would be landfilled in any event, total volume of landfill material would be reduced by the quantity of sand replaced.

Secondly, the most problematic sand material handled by foundries are those fine-grained sands with American Foundry Society (AFS) grade fineness numbers higher than 90. These sands have nearly 80 percent of their grains smaller than 140 U.S. Mesh. This is the sand that poses the greatest threat of dusting during handling and of inhalation by foundry workers. Since fly ash is extremely fine, it possibly can replace these very fine sands. The noncrystalline nature of these ash materials could also reduce or eliminate the concern for crystalline silica exposure in applications using fine foundry sands.

Third, ash products have a considerably lower bulk density than virgin sands. If they prove commercially suitable as a replacement for sands, the resulting molds will be much lighter than comparable sand molds. Handling the molds would become easier for foundry workers and injuries related to handling the molds would be reduced.

Fourth, because fly ash’s low density, it may provide a much higher insulating value than typical foundry sands. This increased insulation would make it possible to pour thinner sections, particularly in light metal (e.g., aluminum and magnesium) castings without encountering freeze-off during the pour. This possible benefit of fly ash use should be more fully explored in future studies.

**Findings**

The Energy Industries of Ohio demonstrated that fly ash could be used as a replacement and filler for foundry sands for both mold and core applications. Molds made from fly ash were successfully poured in both ferrous and nonferrous alloys. For green sand applications, fly ash in varying amounts was found to be suitable as a substitute for traditional foundry sand.

An even more significant finding was the ability to use fly ash in chemically bonded (dry sand) types of applications substituting for 100 percent of the traditional foundry sand. The benefit for using fly ash in these types of applications lend themselves to being used for cores that are currently produced, used once, and then landfilled in many automotive applications.

The project’s demonstration of the the acceptability of fly ash as a substitute for foundry sand points the way to a very promising new application for fly ash.

For more information about this CBRC Project #CBRCE42, visit the CBRC Web site at www.wvori.nrce.wvu.edu/cbrc, or contact the CBRC at (304) 293-2867.
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is the primary binding agent for the grouts. However, ettringite is expansive, and if it continues to form to the point of breaking up the chemical matrix, the grout will become soluble in water.

Normally, as the grouts mature, there is an increasing contribution to the cementing action from calcium silicate hydrates and aluminosilicate hydrates, closely related to the binding phases in portland cement concrete. Continued strength gain and ettringite formation in this particular PFA-FBC system is restricted by the relatively low lime availability in the North Branch FBC ash so durability of the grout is not expected to be a problem but it is being monitored in-situ at Winding Ridge and will be the subject of accelerated weathering experiments at Temple University.

The Path Forward

Completion of phase 1 of the Siege of Acre Project has provided an excellent basis for continuing pre-injection monitoring, planned grout injection, and post injection monitoring. PPRP has made a preproposal to CBRC for assistance in funding phase II of the project with the intention of completing grout injection in 2003 or 2004.

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References


For more information about this CBRC Project #CBREC15, visit the CBRC Web site at www.wvwi.nrcc.wwv.edu/cbrc, or contact the principal investigator, Paul Petzrick, at (410) 260-8669; e-mail ppetzrick@dnr.state.md.us.
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