FLYASH GROUT TESTING IN A SIMULATED WET MINE ENVIRONMENT[1]

Presented by

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ABSTRACT

The Abandoned Mine Lands (AML) Division of the North Dakota Public Service Commission (PSC) has been conducting underground mine filling projects since 1983. The intent of these projects is to protect roadways and residential areas from subsidence produced by collapsing underground lignite mines.

North Dakota's AML Division contracted a material testing engineering firm to research the contaminating potential, physical and geochemical properties of flyash-based grouts injected into a simulated wet mine environment. The project was initiated to find a suitable replacement for Portland cement in grout mixtures due to the high cost of cement. The laboratory testing equipment was designed to simulate a worst-case scenario wet underground mine. Design of the pumped grout mixture is considered by AML staff as one of the most important aspects of subsurface reclamation projects. A grout mixture should be designed to maximize pumpability, flowability and strength. Coal combustion residual ash (flyash) has been used extensively as a cement replacement in grout being injected into dry mines in North Dakota. Until now, North Dakota's State Health Department has not allowed the use of flyash-based grout in wet mine environments.

From 23 separate grout mixtures tested in mine emulation units, one particular mix design was chosen superior in terms of pumpability, strength, least degradation to ground water, and cost. The grout testing project was considered a success and the use of two types of flyash for injection into wet underground mines was approved by the State Health Department. The grout testing project was completed in four months at a cost of $60,000. The project generated a 150 page report delineating leach test analyses of the set-up grout cylinders, chemical analyses of water samples taken at various intervals during the project, grout strengths achieved at various intervals, conclusions and recommendations.

Additional Key Words: Underground Mine Reclamation, Ground Water, Leaching

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INTRODUCTION

In 1980, North Dakota conducted an inventory of abandoned surface and underground mine sites in the state. Information concerning abandoned mines was obtained through literature search of mine inspection reports, available mine maps, field reconnaissance and interviews. The inventory categorized 616 AML sites in the state and prioritized many of them as potentially hazardous to the health, safety and general welfare of the public. Since the original inventory, many additional mines have been identified. It is now projected that there are more than 2,000 abandoned mine sites in the state.

Mining for lignite coal in North Dakota is documented before the turn of the century. Most of the underground mines utilized the room and pillar method of coal extraction and a few underground mines utilized the panel and stub entry mining methods. Historically, most lignite was utilized as fuel for small power plants and local home fueling needs. Every year-usually in the spring, additional abandoned mines are discovered when sinkholes are reported, and the list of underground mines continues to grow. Many of these are located near or beneath roads and highways, housing subdivisions, towns and various other facilities and utilities. Generally, underground lignite mines in North Dakota are shallow, averaging 70 feet (21.3 meters) below surface. Approximately 50% of these mines are considered wet. A wet underground mine is one in which water flow is documented during any time of the year. Most of the wet mines in the state, however, contain groundwater to the mine roof or maintain a static water level above the mine roof elevation.

Reclamation of underground mines in North Dakota during the 1980’s was accomplished by utilizing gravity feed backfilling with a sand/water slurry. This method proved successful only if most areas of the underground mines were intact. Mined areas experiencing collapse or partial collapse would not accept the gravity-fed material readily. Most of North Dakota’s abandoned mines now average 60-100 years old and are experiencing moderate to advanced stages of collapse. This condition has led to the transition from gravity fill to pressure-grouting reclamation. With this transition comes a substantial cost increase for reclamation of these abandoned sites. Increased reclamation costs are predominantly due to the higher cost of materials required for pressure grout injection, specifically cement.

North Dakota currently receives 1.5 million dollars annually to administer its Abandoned Mine Lands Program. With much of our construction budget dedicated toward reclamation of abandoned underground mines, a cost effective grout formulation is imperative. The flyash grout testing project was initiated to determine the most cost effective, environmentally safe grout material available for use in dry and wet underground mines.

The flyash grout testing project required the development of an underground mine simulation unit, grout mixing, testing and pumping procedures, and requisite chemical testing procedures deemed necessary to gain approval from the State Health Department for flyash grout injection in saturated underground environments.

BACKGROUND AND OBJECTIVES

Ground work to formulate and test different grout mixtures with varying amounts of flyash from different sources began with the compilation of a Request For Proposal (RFP). The RFP was generated by the AML Division and sent to a number of professional material testing/engineering firms that have routinely bid on previous AML material testing projects. The major obstacle of this project was to develop a laboratory testing methodology that closely simulates actual field conditions of a saturated underground coal mine. All aspects of the grout testing project, including compilation of the RFP, was done in consultation with the State Health Department. AML wanted the State Health Department involved in this project from the start. Their concerns involving injection of flyash into wet underground mines included the potential for leaching of heavy metals (such as lead) and various other secondary chemicals. Final approval or denial of materials to be injected into wet underground mines is given by the State Health Department. Its staff of geochemical and groundwater scientists contributed immensely to the development of this project.

<u>The principal objective of the flyash grout testing project was to develop a grout material and placement methodology that demonstrated the following characteristics:</u>

- A grout material flowable enough to penetrate tight rubble (collapsed mine) conditions
- A grout material easily pumpable through any commercial grout pump
- Laboratory method that simulates placement (injection) of grout into saturated mine conditions
- The effect of water fluid forces on the grout mix (segregation of material components)
- Initial impact on water quality as grout mixes are placed into the water
- Longer term effects on water quality from grout mixes placed in the water
- Curing properties of grout mixes in a saturated hydrogeological environment compared to dry curing and 100% humidity curing
- Leaching characteristics of emplaced/cured grout in a saturated environment

The RFP required prospective engineering firms to provide for laboratory methods addressing the above-listed parameters. Provisions for establishing baseline characteristics of all grout material components was also required. Provisions for establishing and characterizing the water sampling and testing methodology and chain of command were required.

Prospective contractors were given 30 days in which to prepare their proposal. The only proposal received by AML was from Material Testing Services, Inc. of Minot, North Dakota. Once the original proposal was received, meetings were conducted to fine-tune certain aspects of their proposal so that all parties involved were satisfied with the proposed methodologies of sampling, testing, placement, curing and reporting. A revised proposal was found acceptable by all parties and work commenced.

METHODS AND MATERIALS

A total of twenty three (23) separate trial mixes were prepared. The mixes contained varying amounts of flyash, cement, sand, water and superplasticizer (high range water reducer). The RFP required the grout mix components to fall within the following guidelines:

- Flyash to be tested is available at five pre-determined electrical generating stations (Antelope Valley and Coal Creek Stations in North Dakota and PRPS, Boundary Dam and Shand Power Stations in Canada).

- Portland cement shall be either Type I or Type II in accordance with American Society of Testing and Measurement (ASTM) C:150

- Sand (aggregate) shall consist of natural sand having hard, strong, durable particles free from deleterious material. Sufficient sand shall be utilized to achieve a yield of 27 cubic feet/cubic yard in the grout mixes. Fine sand shall have 100% passing the #4 sieve and a minimum of 15% passing the #200 sieve. Medium sand shall have 100% passing the #4 sieve and a maximum of 5% passing the #200 sieve

- Water utilized for grout make-up water will include municipally treated potable water, distilled water and well water

- Superplasticizer shall conform to ASTM C-494 Type F

In an effort to simulate actual field conditions, the various grout mixes were pumped using a hand operated pump through 20 feet (6.1 meters) of hose into a "mine emulation" unit and storage container. The emulation unit (See Figure 1.) was immersed in water in the storage container. The mine emulation unit was constructed of two PVC 45 degree elbows, a short section of four inch PVC pipe, two manufactured plastic ends, eight 1/4 inch (.64 cm.) PVC rods 16 inches (41 cm.) in length and a section of plastic screen. The chamber allowed more than 50% of the grout in the unit to be exposed to water in the container. The elbows and pipe section were solid wall to insure that only the grout in the mine emulation unit was exposed to water.

The storage containers were 29 gallon (109 liter) commercial aquariums which provided for optimum viewing during pumping and curing of grout specimens. Each storage container was fitted with a plexiglas cover and a vacuum/sampling valve. The plexiglas cover and vacuum sealing was deemed necessary to thwart the potential for algae growth, which may have skewed water chemistry results. The sampling valve was utilized to collect water samples without possibility for contamination by human touch or the air. Submersible pumps were installed in each unit for groundwater movement simulation.

The grout mixes were cured for 56 days. During that time period water samples from the storage containers were collected and tested at ages 1 hour, 28 days and 56 days. The plastic grouts were tested at production for temperature, slump, air content, unit weight and yield. Grout cylinders were cast and compressive strength tests of the grout were performed at ages 7, 14, 28 and 56 days. Chemical composition and compression strengths of the hardened in-situ grout mixes were also analyzed at the 56 day age. All of the mixing, pumping and test procedures were videotaped.

The cement, superplasticizer and five different types of flyash were sampled and tested for chemical composition at the start of production. Mechanical analysis by hydrometer was performed for each flyash source. Each water source (municipally-treated, distilled and well) was sampled and tested for chemical composition prior to mixing the grout.

Figure 1. Mine Emulation Unit

Tests performed on water samples included analysis of pH, specific conductance, phenolphthalein alkalinity, bicarbonate, carbonate, hydroxide, total dissolved solids, total suspended solids, sulfate, boron, chloride, nitrate as N, nitrite as N, fluoride, calcium, magnesium, sodium, potassium, total hardness as $CaCO_3$, hardness in grains/gallon, cation summation, anion summation, sodium adsorption ratio, aluminum, arsenic, barium, cadmium, chromium, copper, iron, lead, manganese, mercury, selenium, silver and zinc.

Approximately eight cubic yards of fine aggregate (sand) was placed in bins and loaded into a ready-mix truck and thoroughly mixed. The sand was then placed in a covered storage bin until used. The sand was sampled from the storage bin in accordance with ASTM D75 procedures. Initial testing of the sand included moisture content, gradation, shale content, specific gravity and unit weight. Gradation and moisture tests were then performed daily during mix production to insure uniformity of the sand. The sand was also screened through a #4 sieve prior to use in the mixes.

The grout mixer, grout pump, hose, shovels, aquariums, mine emulation units, storage containers and all hand tools were steam cleaned prior to the production of each mix. All technicians involved with the mixing and testing of the grout wore latex gloves.

The mine emulation units were assembled and placed in the storage containers (aquariums). One hundred pounds of the source water was added to each storage container prior to pumping the grout into the emulation unit.

GROUT MIXING, GROUT TESTING AND PUMPING

The grout ingredients were placed in a commercial mixer. Mixing continued until a consistent mix was obtained. The plastic grout was tested for slump, air content (by Chase indicator), temperature and unit weight prior to pumping and again at the hose discharge end. Twenty four grout cylinders were cast for each mix for compressive strength testing. Twelve of the twenty four were moist cured at 70 degrees F (21 degrees C) and twelve were dry cured. The dry cured cylinders were placed beside the corresponding storage unit (aquarium). The compressive strength of the cylinders were tested at ages 7, 14, 28 and 56 days. Three dry cured cylinders and three moist cured cylinders were tested for each mix at each age listed.

Twenty two of the grout mixes were pumped with a Kenrich Model GP-2 hand grout pump through 20 feet (6.1 meters) of 1-1/2 inch (3.8 cm.) diameter hose into the mine emulation unit. One mix was pumped directly into the storage container (aquarium). The volume of grout pumped into each unit was kept constant by using the same number of pump cycles for each mix. The pump cycles were calibrated during the test mixes by pumping the grout into a known volume container and counting the cycles it took to fill the measure. Two test mixes were sampled, pumped and tested to work out the bugs before actual production started.

Grout specimens were cut from the hardened samples in the emulation unit at the 56 day age and tested for compressive strength. At the completion of the pumping, the aquarium was covered with plexiglas. Each unit was sealed with 100% clear silicon and then vacuum sealed.

CHEMICAL TESTING OF STORAGE WATER AND GROUT

Water samples were taken through the valves in the plexiglas covers with the aid of plastic and glass tubing. A syringe was used to start a siphon. The water was placed in sample jars provided and delivered to the analysis laboratory within 24 hours. After sampling, the storage containers were vacuum sealed again. Water samples were taken at 1 hour, 28 days and 56 days for each storage container.

The submersible pumps were turned on for two minutes every day to simulate groundwater movement. All the pumps were on the same electrical circuit and controlled with one switch to insure that the water circulated at the same time ever day for all units.

After the compression test of the hardened grout from each emulation unit, pieces of the grout were collected and tested for chemical composition by using the Shake Extraction method in conformance with ASTM 3987.

DISCUSSION AND CONCLUSIONS

The flyash grout testing project was considered a success. One grout mix was chosen superior to all others in terms of flowabilty, pumpability, non-segregation of material while pumping and during injection, compressive strength achieved and leaching characteristics in water. The grout mix chosen allowed for the use of flyash from two different electrical generating plants in North Dakota. The State Health Department did not specifically reject or deny the use of particular grout mixtures. They did, however, state their preference of grout mixtures to be utilized as well as other acceptable grout mixtures generated from the testing project. Specific data on water sample analysis, leachate analysis and grout strengths achieved are much too numerous to mention in this publication and are included in a 150 page report of the grout mix research project. Grout mixtures classified as preferred and those deemed acceptable by the State Health Department were based on the state of North Dakota's Drinking Water Standards. Drinking water standards vary from state to state and approval for usage of specific flyash grout mixtures will vary depending on each state's drinking water standards.

<u>The chosen grout mix consists of the following</u>:

- **Portland cement -** Type I or II, 100 lb. per cubic yard
- **Flyash -** from an approved source, 600 lb. per cubic yard

- **Superplasticizer** - 70 oz. per cubic yard
- **Sand** - 100% passing #4, 40-80% passing #30, minimum of 10% passing #200
- **Water** - preferably treated water in a sufficient amount to achieve a 10-1/2 inch (26.7 centimeter) slump for most injection applications

Compressive strengths achieved from the chosen grout mixture in pounds per square inch (psi) unconfined compressive strength

	7 days	**14 days**	**28 days**	**56 days**	**Chamber (56 days)**
wet cured	195	275	530	1055	325
dry cured	180	300	345	895	

Grout costs for underground mine reclamation projects have been reduced significantly with the use of the above listed grout mixture in both wet and dry underground mines. Previously, a grout formulation with 400 pounds of cement was used. The cost of cement grout to the AML Division averaged $47.50 per cubic yard. The cost of the approved flyash grout, containing only 100 pounds of cement and 600 pounds of relatively inexpensive flyash, (2 projects) averaged $34 per cubic yard. This represents a cost savings of $13.50 per cubic yard. For a 20,000 cubic yard pressure grouting reclamation project, the savings on grout costs alone are about $270,000.

As a contingency of the grout approval process, the State Health Department required a minimum compressive strength of 150 psi (10.55 kilograms/square centimeter) be achieved. Also, injection of grout into wet underground mines is to proceed utilizing a bottom-up tremmie method. Tremmie grouting is accomplished by injecting the grout material into subsurface rubble or voids in a sequence beginning at the bottom of the void and progressing upward in approximate two foot increments. Upon completion of each two foot grouting interval, the injection pipe is tremmied (lifted up) in two foot increments. The requirement for utilizing a tremmie grouting method in saturated mines is to minimize surface exposure of grout to the groundwater during injection processes.

Most of the grout testing project concentrated on flyash that is available in North Dakota. Generally, grout mixes utilizing flyash leached less trace metals and secondary chemicals than a cement-only grout. Cement grouts resulted in higher pH levels in the water than flyash grouts. This may tend to mobilize certain constituents more readily. According to chemical analysis results, trace metals were generally higher in grout mixed with Coal Creek flyash than the Antelope Valley flyash. With the exception of aluminum, test results show that the amounts of specific metals do not exceed limits set forth in the Safe Drinking Water Act Standards for either the Coal Creek or Antelope Valley flyash.

In comparing the secondary chemicals, Antelope Valley flyash mixes trended higher than mixes with Coal Creek flyash. The secondary chemicals in the Antelope Valley flyash mixes in many cases did exceed the Safe Drinking Water Standards but the

Coal Creek Flyash did not. It should be noted that these tests were performed in an isolated closed system that did not allow for any dilution that may occur under actual conditions.

The use of superplasticizer in the grout mixes does not appear to affect the quality of chemical composition of the groundwater. The use of superplasticizer reduces the water/cement ratios and increases the compressivie strengths of the grout mixes.

The flyash grout testing project was completed in four months at a cost of $60,000. The cost of this project was recouped through grout cost reductions in our first pressure grouting project with the approved flyash grout mix.

RECOMMENDATIONS

Agencies interested in performing a grout testing project similar to that which is described, should work closely with the appropriate Health Regulatory Authority from the beginning.

Flyash products differ markedly depending on a number of conditions such as type of coal, specific chemistry of the coal and type of burning system utilized at the electrical generating plant. It is recommended that any flyash considered for use as a grout admixture be thoroughly tested in a similar manner to that which has been described to attain as much information as possible. Your State Health Regulatory Agency will inform you of flyash sources most likely amenable to testing and usage in saturated underground mining environments. They should be able to supply you with a list of flyash sources utilized commercially in pozzicrete by ready-mix firms.

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