Use of Calcium-Based Products to Stabilize Ponded Coal Ash Techniques and Results

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Abstract

The recent failure of a dam for a coal ash impoundment has heightened the concern for this method of coal ash storage within the power industry and regulatory agencies. Ponded ash if disturbed or if containment is lost can become unstable structurally and it can flow, causing physical damage and/or environmental contamination of adjacent lands and waters. Because of the number of ponds in existence and the volume of material that they collectively contain, strategies are emerging to assist utilities to manage their risks. Calcium-based materials such as lime and its co-products have been used for decades to stabilize clay soils and fixate undesirable materials. Because of similarities between clay minerals and coal ash, strategies can be implemented similar to soil stabilization that improve the structural properties of coal ash and improve its storage prospects. The work presented will demonstrate methods of preparing mixtures of ponded coal ash stabilized with calcium-based products to take advantage of the pozzolanic properties inherent in fly ash to produce an engineered structural fill material. This engineered fill material can be used in the construction of dams for impoundments, for structural toe berms for dry ash landfills, as a structural mat to bridge over saturated, low bearing strength, ponded ash, and as a capping material to prevent water infiltration into the ash landfill, thus limiting the leachate from the coal ash. The work presented will provide data demonstrating the structural properties from stabilized pond ash design mixtures.

Calcium Based Stabilization

For many decades lime and its co-products have been contributors to geotechnical projects for uses ranging from drying wet construction sites to stabilizing clay soils that are otherwise unsuitable to build upon. The chemistry of soil stabilization is well known and based upon the fact that, like coal ash, clay is a pozzolan. Several key elements including heat production during lime hydration; elevated pH; the availability of calcium, silica, and alumina from the clay; and, the availability of water combine to create pozzolanic cements. With the exception of adequate calcium, those same pozzolanic building blocks are all abundant in coal ash ponds. In the case of clay stabilization the soil system is flooded with calcium products that produce 490 Btu/lb of heat during hydration. The hydroxyl ions resulting from the quicklime hydration elevate the pH to approximately 12. Since the silica and alumina components of clay are soluble above pH 10 they become available to react with an abundance of calcium ions and water to form the pozzolanic cements, calcium-silicate-hydrates (CSH) and calcium-aluminate-hydrates

(CAH). Those cements are water insoluble and can produce strong, permanent matrices. Clay soils properly stabilized with lime products are transformed into new materials that exhibit significant permanent strength.

Like the natural pozzolan clay, coal ash contains significant fractions of silica and alumina that can become available for reaction at an elevated pH. Although it contains a small fraction of calcium hydroxide the percentage is unlikely to be great enough to initiate the formation of significant cementitious products. Consequently, it is necessary to supplement the coal ash with a calcium-based product based upon lime. When calcium-based products are introduced correctly the water content of the ponded coal ash can be reduced and the solids agglomerated into cementitious products that are stable and have structural properties that simplify handling the material. Stabilized coal ash ponds can be used as bases for on-site landfills. It is also possible to produce materials that can be used for engineered embankment or backfill applications.

Several attributes of lime stabilization conveniently match the requirements of ponded coal ash stabilization. For example, the strongly exothermic reaction during the hydration of one pound of quicklime (CaO) can raise the temperature of 3.4 lb of water from room temperature (70F) to boiling (212F), transforming it into steam that dissipates into the air. In addition to that reduction of pond water, the formation of pozzolanic cements consumes water, and the optimum moisture content of the pozzolanic cements created by the reaction of lime with coal ash increases compared to the original material. In other words the solid matrix of the transformed coal ash has an increased moisture holding capacity than ash prior to treatment.

Another important characteristic of calcium-based products based upon lime is that the treated ash can be remixed and manipulated over time as is necessary for the target application. As long as the system’s pH remains above approximately 10 silica and alumina will continue to combine with calcium and water to form pozzolanic cements. As has been demonstrated many times when lime has been used to stabilize clays the elevated pH and formation of cements can continue for months, if not years.

Testing

Since the chemistry of coal ash varies according to coal source and the presence of outside contaminants it is necessary to characterize ash to evaluate its potential for structural improvement. Samples should be collected from several locations and depths in each pond to try to capture potentially important material changes that might have occurred over time. At the very least ashes should be tested for percentages of silica and alumina oxides, along with organic (humic) matter and moisture content (percent solids). Generally, available calcium hydroxide is disregarded since it is rarely sufficient to produce significant pozzolanic cements. If there is reason to suspect that heavy metals or other contaminants are present in the ponds testing for those concentrations can be included, as well. The characterization testing provides the basis for selecting an additive blend and a strategy that is best suited for the proposed application.

After the coal ash is characterized physical testing basically mirrors the geotechnical tests used to evaluate fine grained soils. Moisture density curves are created to determine the optimum moisture content and unit weight of the ash. Unlike soils coal ash curves are difficult to determine since ash becomes challenging to compact at moisture contents above optimum. It is important to have the moisture-density data as guidance for successful blending of calcium-based products with the coal ash. When lime is added to clay soils those soils are chemically transformed into new materials which have lower unit weights and higher optimum moisture contents. Likewise, coal ash becomes lighter and stronger per unit volume as pozzolanic cements form, and it becomes less sensitive to water (higher optimum moisture content). The following test results using ash from an Eastern power plant and lime from Chemical Lime Company's St. Genevieve, MO manufacturing facility illustrate the procedures and typical results.

A. Characterize the Coal Ash

%	Sample 1	Sample 2	Sample 3	Sample 4
SiO_2	48	47	49	47
Al_2O_3	19	22	21	22
Organic matter	2	3	2	3

The analysis shows that the ash contains ample pozzolanic compounds to form cements. The organic content indicates that some lime will be sacrificed satisfy the cation exchange capacity of the organic material prior to its reaction with the coal ash pozzolans.

B. Moisture-Density Relationships and Unconfined Strength

Sample 1

Treatment	None	2% Lime	3% Lime	4% Lime
Opt. M.C. (%)	24	26	25	26
Max. Density (lb/ft^3)	86	84	85	84
UCS (psi)	24	147	344	505

Sample 2

Treatment	None	2% Lime	3% Lime	4% Lime
Opt. M.C. (%)	33	36	36	36
Max. Density (lb/ft^3)	77	75	75	74
UCS (psi)	55	174	201	256

Sample 3

Treatment	None	2% Lime	3% Lime	4% Lime
Opt. M.C. (%)	29	32	30	31
Max. Density (lb/ft^3)	78	79	78	77
UCS (psi)	38	122	303	338

Sample 4

Treatment	None	2% Lime	3% Lime	4% Lime
Opt. M.C. (%)	34	38	37	38
Max. Density (lb/ft^3)	74	72	72	72
UCS (psi)	55	133	174	247

The example data demonstrate a dramatic growth of strength with the addition of increasing percentages of lime. In addition, the optimum moisture contents increased and unit weights decreased to lesser extents after the addition of lime. The changes in moisture content and unit weight occurred within the first few hours after mixing. The strength gain was measured after 48 hours of curing in sealed containers at 120F. The accelerated curing provides a prediction of strengths that may be achieved after several weeks of curing at ambient temperatures in the field.

The pH of some of the cured samples was measured to assess the potential for continued strength gain. In each instance the measured pH exceeded 11.75 indicating that pozzolanic cements would continue to form, further improving the coal ash properties over time.

Uses for Stabilized Coal Ash

Stabilizing coal ash with calcium-based additives can produce products appropriate for several different applications depending upon the ash and the amount of additive that is used. Fundamentally, the water content of ash ponds can be reduced and the solids increased by the exothermic hydration of calcium oxide and the reaction of the calcium ions with silica, alumina, and water. The combination of drier material and pozzolanic strength can produce a product that can bridge over and contain lower strength coal ash. That improvement will also enable the treated ash to be handled and stacked more efficiently. By increasing the percentage of the calcium-based blend and the intimacy of mixing higher compressive strengths and lower permeability of the stabilized ash can be achieved broadening its potential applications as a structural embankment, fill, or capping material.

A potentially attractive option for utilities faced with converting from wet CCP management to dry management strategies would be to stabilize the ponded CCPs in situ and create a foundation for a new dry disposal facility. This would minimize the disturbance of land area and provide an economic solution to the conversion.

Procedures for Stabilizing Ponded Coal Ash

Procedures used to achieve the target improvements will vary depending upon the accessibility of the ponded ash, its moisture content, and available mixing equipment. To create a working platform or cap on a coal ash impoundment a simple technique is to spread and mix the calcium-based blend into the ponded ash using a low ground pressure track hoe operating from the access road on the top of the impoundment dam. The depth of mixing should be based upon laboratory testing and the use of a conservative application rate in the field because of the crude mixing technique. As the ash on the surface is dried and begins to harden the track hoe can proceed out onto the pond expanding the cap. As the treated material solidifies the surface should be kept moist to minimize cracking and light compaction should be applied to improve the contact between particles. That method, while simple, is not very efficient and is likely to waste a significant quantity of the calcium additive.

Particularly where there is room to stockpile treated material, coal ash can be pumped from an impoundment and conveyed to a mixing device such as a pugmill where it can be mixed with the calcium blend and stockpiled to partially dry and begin forming pozzolanic cements. When the treated materials have improved enough that they can be easily handled they can be installed in the pond as a working platform or a capping layer. As described above the surface should be kept moist to minimize cracking and lightly compacted to improve contact and bearing capacity. The thickness of the layers should be based upon an engineering design that takes into account the time-dependent strength increase.

In areas where the coal ash can be spread and worked outside of the pond conventional soil stabilizing equipment can be used to blend the materials. Dry calcium-based additive can be spread across a mixing table and blended with the ash using commonly available roto-mixers. Additional layers of ponded coal ash can be added to the stockpile, mixed and allowed to cure until they are ready to be transported to their final location. That location could be a capping layer, a structural fill, or an embankment depending on the selection of additive blend and addition rate to achieve appropriate engineering properties. This particular strategy takes advantage of an important property of lime-based additive blends. As noted earlier, the formation of pozzolanic cements and the achievement of permanent material strength is a function of maintaining high pH in the stabilized mixture. There have been many instances when lime has been mixed with clay soils where treated materials have been stockpiled for weeks or months before use. With the addition of an appropriate amount of a calcium-based blend the pH in the stockpile has remained elevated insuring an excellent final product.

In cases where deep mixing is desirable track mounted auger mixers are available that can introduce chemical blends to a desired depth into a pond. That technology is European in origin and was developed, in part, for soft soil engineering. Deep mixing has been used in the U.S. for years and specialty contractors own a variety of types of equipment and are experienced in using the techniques under challenging conditions. It is likely that significant permeability improvements could result from the use of deep mixing.

As the test results from the example coal ash samples demonstrated, with additional engineering many lime coal ash blends can be designed to be incorporated into dam and dike construction to create additional on-site storage. As ponds are filled with lightly treated ash, layers of more heavily stabilized material might be added to provide incremental stability to the total system. Finally, when ponds or landfills are retired it may be possible to cap them with low permeability lime/coal ash layers to minimize water intrusion and leaching.

Finally, given the wide range of strengths that may be achieved by blending lime-based additives with ponded coal ash some engineered products might be used as select fill in embankments or controlled low strength backfill (CLSM) in trenches elsewhere in the construction industry. Naturally, as the importance of the application for which the stabilized coal ash is used increases so too must the extent of engineering design and testing.

Conclusion

The recent failure of a coal ash impoundment has increased concerns about that common method of storage. Partly as a result of those concerns new strategies for managing those facilities and the materials that they contain are emerging. One of those strategies is to stabilize the pozzolanic ash using calcium-based materials containing lime. A broad range of applications can be envisioned depending on the target application and the calcium-based blend that is selected. Several construction strategies can be employed depending upon site specific circumstances and the engineering properties that are being sought. As the importance of the engineering application using stabilized coal ash increases more comprehensive tests and evaluations should be conducted. Finally, as more and more attention is given to implementing Green Engineering, new applications will emerge that can take advantage of the chemistry and compatibility of calcium-based additives and coal ash.

Bibliography

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