Stabilization of Soil with Self-Cementing Coal Ashes

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INTRODUCTION

The combustion of subbituminous coals in electrical generating units produces a fly ash that has proven benefits for the construction industry. Fly ash consists of the inorganic material within the coal that has been fused during combustion, solidified while suspended in the exhaust gases and collected by electrostatic precipitators. Bituminous coals have low concentrations of calcium compounds and the ash produced (Class “F”) exhibits no self-cementing characteristics. The addition of activators such as lime yields cementitious products so that this material can be used for a wide range of soil stabilization applications. Subbituminous coals have higher concentrations of calcium carbonate ($CaCO_3$); thus, the ash (Class “C”) produced during combustion is rich in calcium, resulting in the self-cementing characteristics. Since Class “C” fly ash is self-cementing; activators such as lime or Portland cement are not required. Upon exposure to water, Class “C” fly ash hydrates forming cementitious products similar to those produced during the hydration of Portland cement. This property makes the self-cementing fly ash a very effective and economical stabilization agent for use in variety of construction applications.

FACTORS INFLUENCING FLY ASH PROPERTIES

The properties of fly ash are dependent on several factors with the primary factors including the 1) coal source and 2) boiler and emission control design. These primary factors dictate the mineralogy and properties of specific fly ash sources.

Coal Source

The coal source dictates the amount and type of inorganic matter within the coal and in turn the constituents within the fly ash. Bituminous and many lignite coals have low concentrations of calcium compounds; thus, the ash (Class “F”) produced does not exhibit self-cementing properties. However, with the addition of an activator such as lime, a pozzolonic reaction will occur in the Class “F” fly ash producing cementitious products. Subbituminous coals typically have higher concentrations of calcium carbonate and the Class “C” fly ash produced typically contains 20 to 30% calcium compounds.

Boiler and Emission Control Design

While the coal source dictates the chemical constituents of a particular fly ash, it becomes apparent that boiler and emission control design as well as plant operation also have a major influence on the crystalline compounds within the fly ash. The hydration characteristics of a fly ash are dictated by the rate at which the fused particles are cooled. During combustion, the inorganic matter in the coal is fused and transported from the combustion chamber as small particles, suspended in the exhaust gases. When these particles are cooled rapidly, the fly ash produced has a noncrystalline (glassy) or amorphous structure. When the particles are cooled at a slower rate, the fly ash produced has a more crystalline structure. Since the crystalline compounds provide the self-cementing characteristics of the fly ash, the boiler and emission control design as well as plant operation influence the degree of crystallinity, which in turn determines the hydration characteristics of specific fly ash sources.

Fluidized bed or dry scrubber systems are used to limit the sulphate emissions in the exhaust gases while burning high sulfur coals. Although some of the hydration reactions and physical properties of these combustion products are similar to those of Class “C” fly ash, the higher concentration of sulfate compounds introduces additional chemical and physical constraints which are not shared by self-cementing subbituminous coal ashes. The sulfate content of these ashes typically exceeds 10 percent, indicating the effectiveness of the SO_2 removal technology. Ash having a high sulfate content often will have an initial strength gain similar to those achieved with subbituminous coal ash; however, the ash can also produce highly expansive sulfate reactions which can, and have, caused substantial damage to pavement and building structures supported by materials stabilized with high sulfate ash.

STABILIZATION CHARACTERISTICS

An effective method for evaluating fly ash stabilization is to determine the moisture-density and moisture-strength relationship for the fly ash treated materials. This is accomplished by adapting American Society of Testing Materials (ASTM) C-593 (Standard Specification for Fly Ash and Other Pozzolans for Use with Lime). Specimens are compacted in molds in accordance with ASTM D-698 (Standard Proctor Compaction). Following compaction, the specimens are extruded from the mold, wrapped to prevent moisture loss and cured at a temperature of 100° F for seven days. The specimens are then capped with high strength capping compound and the unconfined compressive strength determined.

We have observed that for all fly ash materials, a discrete optimum moisture content exists for both maximum density and maximum strength. Optimum moisture content for maximum strength typically occurs at moisture contents of 1 to 7 percent below the optimum for maximum density. These properties have been found to be a practical method for evaluating the hydration characteristics of specific fly ashes and to achieve optimum benefits for a stabilization application.

EFFECTS OF COMPACTION DELAY

Since fly ash alters the compaction characteristics of soils, a moisture-density relationship must be established for the specified fly ash content. The change in compaction characteristics, for materials compacted immediately after incorporation of the fly ash is primarily due to altering of the material's gradation. When compaction is delayed, as occurs in normal construction operations, the fly ash hydration products begin to bond soil particles in a loose state and these bonds must be disrupted to densify the material. Therefore, a portion of the compactive effort is used to overcome the cementitious bonds with the remaining energy to compact the mixture. When compaction is delayed 1 hour after incorporation of the fly ash, maximum densities can decrease up to 4 to 10 pcf (0.6 to 1.6 KN/m^3) depending upon the mineralogy of the fly ash. In addition to altering compaction characteristics, the compaction delay also reduces the maximum compressive strength obtained for the fly ash treated material. The strength reduction is the result of cementitious bonds that have been disrupted during compaction and reduced number of intergranular contacts.

The reduction in maximum density and strength is dependent on the fly ash hydration rate and can vary significantly between different ash sources. Compressive strength of the fly ash treated material is also influenced by the moisture content at the time of compaction. The optimum moisture content must be defined for the specified fly ash contents. Typical moisture-density and moisture-strength relationships for a fly ash treated material are presented in Figure 1.

Construction specifications commonly require that mixing, compaction, and final shaping be completed in one or two hours of initial mixing. Strength and compaction characteristics at no delay define optimum properties of the fly ash treated materials, and the characteristics determined at the specified compaction delay define the minimum properties of the material that will be obtained in the field.

RETARDERS

The rapid rate of hydration exhibited by the Class "C" fly ashes can in some applications be controlled by the use of retarders. However, these retarders tend to be costly and are typically not economically practical for most applications. Retarders, such as modified lignosulfonate, have been found to enhance the cementitious properties of the fly ash in some applications.[1] The ash hydration chemistry for each of the sources is unique and the influence of a retarder can differ significantly for each of the ashes. No universal retarder exists for all ashes.

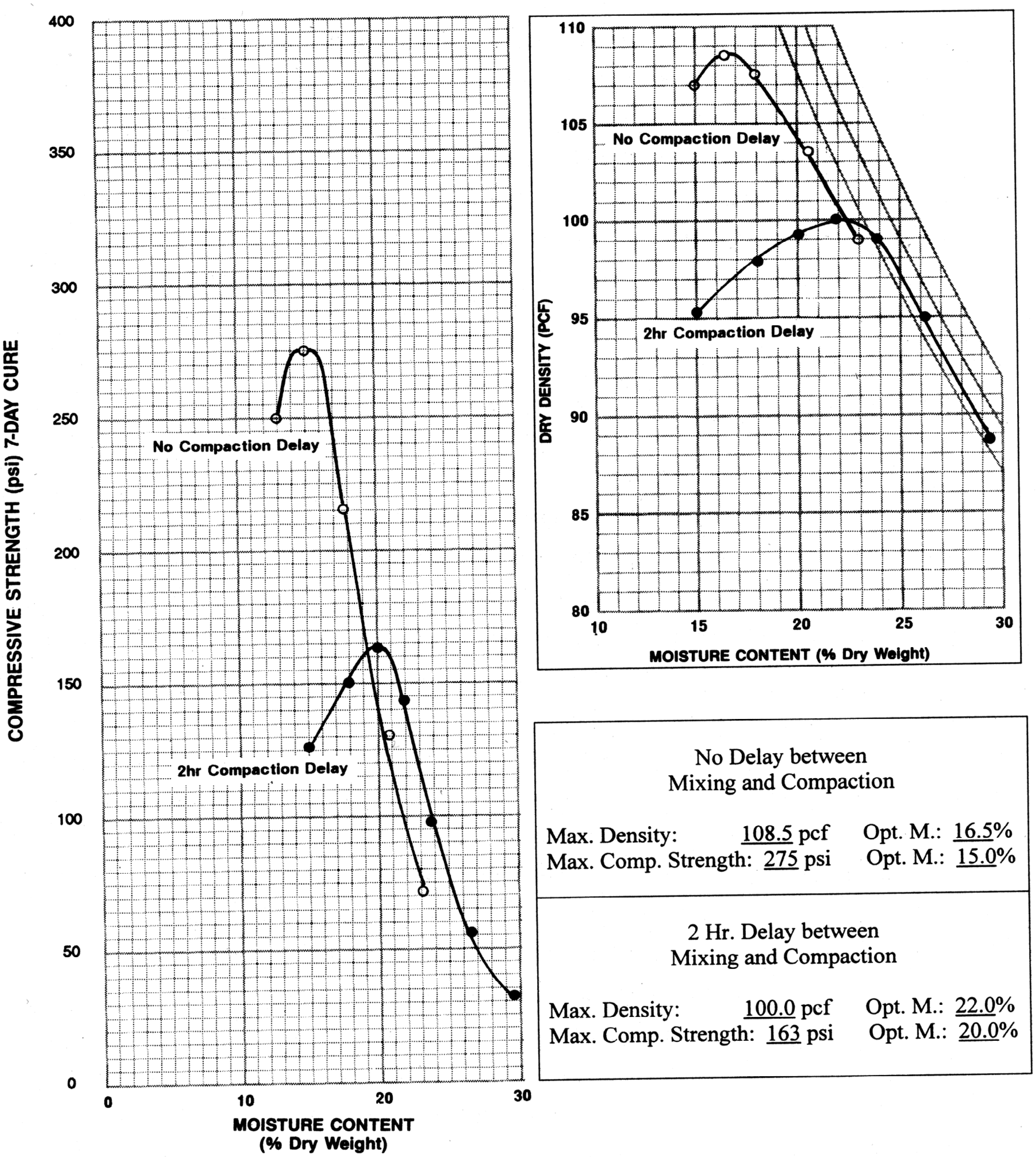

FIGURE 1. MOISTURE-DENSITY & MOISTURE-STRENGTH RELATIONSHIP FOR A FLY ASH TREATED LEAN CLAY

FLY ASH STABILIZATION APPLICATIONS

Self-cementing Class "C" fly ash has been demonstrated to be an effective and economical stabilizing agent for a wide variety of construction applications. Most fly ash stabilization applications require fly ash contents ranging from 12 to 15% (dry weight basis); where as, cement or lime stabilization typically requires contents ranging from 3 to 7 %. Even with the addition of larger quantities of ash to achieve the stabilization required, the fly ash treatment is generally more economical than the lime and cement alternatives. Typically, the delivered cost of fly ash will range from $18 to $30 per ton and depends on the ash source and haul distance.

Applications for self-cementing fly ash generally include:

- Drying of the soil to facilitate compaction
- Treatment of the soils to reduce shrink-swell potential
- Stabilization of the soil to improve the engineering properties, i.e., increase strength or subgrade capacity

Treatment and stabilization of soils, aggregate base and recycled pavements with self-cementing fly ash has been performed on numerous construction projects. Each project required extensive laboratory and field testing that provided comparative data for a range of material conditions. This data provides an opportunity to evaluate the effectiveness of treatment and stabilization with self-cementing ashes.

Drying Agent

Class "C" fly ash can be used as a drying agent to facilitate compaction of materials. During spring and fall construction, compaction of soils is often hampered by the inability to reduce the moisture contents of the soils to levels suitable to achieve proper compaction. The incorporation of Class "C" fly ash into the soil provides an immediate drying effect and allows final compaction to be completed within a relatively short period after incorporating the fly ash. The amount of fly ash need for drying is dependent on the materials initial moisture content and the optimum moisture required for compaction. Soil moisture contents can readily be reduced by 10 to 20 %.

Reduction of Shrink-Swell Potential

Fly ash treatment of expansive clay soils has, for the most part, replaced lime treatment in areas where self-cementing ashes are available. While the mechanism of the ash treatment is similar, there is some difference in the way that shrink-swell potential is reduced. Only a limited amount of the free lime (CaO) is available in the fly ash for agglomeration and flocculation of the clay minerals. Consequently, the reduction in soil plasticity achieved through fly ash treatment is generally less than what can be achieved through lime treatment. A major portion of the calcium in the ash is in a crystalline form that hydrates when exposed to water and forms cementitious products. The reduction in swell potential achieved through ash treatment appears to be related to mechanical bonding rather than ion exchange with the clay minerals. Therefore, stabilization of clay soils with self-cementing ash appears to be less influenced by the reactivity of a particular soil. While soil pH and organic content can influence the strengths achieved, other factors that influence strength of lime treated soils appear to have less impact on the strength development of fly ash-treated soils.

Unpublished studies for the Heartland Racetrack in Topeka, Kansas included an extensive series of tests on expansive clays and weathered shale. The study indicated that the swell potential of these materials could be significantly reduced by the addition of a self-cementing ash. A series of fly ash treated and untreated samples were compacted at a range of moisture contents. All specimens were compacted in the same manner (Standard Compaction effort) and cured for 7 days prior conducting the swell tests. Swell tests were performed on treated and untreated specimens trimmed from the compacted samples with a surcharge pressure of 100 psf (4.8 kPa) in general accordance with ASTM D 4546. Using fly ash treatment of expansive soils, the shrink-swell potential of material is generally reduced to levels comparable with lime treatment.[2]

Stabilization – Increase in Strength or Subgrade Support Capacity

Self-cementing fly ash can be used to improve shear strength and subgrade support capacity of cohesive soils. This application requires a more thorough understanding of the ash hydration process and strict control of construction operations to achieve the properties (strength, etc.) required by the project. Construction procedures that must be controlled include the method of incorporation, moisture control and compaction delay. Typically, the use of a pulvamixer is required to provide uniform blending of the fly ash and water throughout the stabilized material in the specified time.

<u>Subgrade Stabilization</u>

Stabilization of cohesive soils used for pavement subgrades with self-cementing ashes can increase the California Bearing Ratio (CBR) by up to 20 times and increase the unconfined compressive strength by 3 to 12 times the strength of the untreated material.[3] The increase in unconfined strength is influenced by the length of compaction delay and the hydration characteristics of the specific ash used for stabilization.

In addition to increasing strength, the deformation characteristics of the stabilized material will also be improved, in that the stress-strain modulus value will be greater resulting in decreased deformation under the imposed loads. Fly ash stabilization of the soil subgrade materials also provides a more stable working platform, which is less susceptible to disturbance by moisture and construction traffic.

<u>Stabilization of Aggregate Base</u>

Use of Class "C" fly ash as a stabilization agent in aggregate base course mixes is hampered by the rapid rate of ash hydration, which makes it impractical to produce the material as a plant mix, even when retarders are used to control the rate of set. However, stabilized aggregate base sections have been successfully constructed with self-cementing ashes using road mix procedures, thereby limiting the time between incorporation of the ash and final compaction. The use of a retarder can also be used to facilitate construction.

<u>Pavement Recycling</u>

Stabilization with self-cementing ashes provides an economical method of recycling flexible pavements that have granular base sections.[4] Existing pavements of this type can be pulverized in-place, sufficient quantities of self-cementing ash and water added, and the resulting mixture compacted to function as a base course having a greater structural capacity than the original pavement section. The recycling process is applicable for existing pavements consisting of thin asphaltic concrete sections (less than 4 in) underlain by a granular base section of variable composition. The granular sections in pavements to be recycled are generally contaminated with subgrade soils, which reduces the shear strength of the granular materials. The gradation of the pulverized materials (including asphaltic bound material), the ash source and construction methods (compaction delay) will dictate the increase in stability achieved through fly ash stabilization. Demonstration projects have shown that recycled sections stabilized with self-cementing ashes can develop unconfined compressive strengths in excess of 800 psi (5.5 MPa) and structural coefficients of 0.15 to 0.25 for use in flexible pavement design.[5]

CONCLUSIONS

Self-cementing Class "C" flay ashes have demonstrated to be an effective and economical stabilization agent for a wide range of construction applications. Construction procedures (moisture control and compaction delay) as well as the rate of ash hydration can greatly affect stabilization process. These conditions must be addressed during construction to achieve the required design strengths. Determination of the moisture-density and moisture-strength relationships of the self-cementing ash treated materials has proven to be a reliable basis for developing mixes and assessing the hydration characteristics of specific fly ash sources.

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