Fly ash generated by power plants as a by-product of coal combustion can be disposed of in municipal solid waste or special waste facilities. In either case, disposal of fly ash by power-plant operators results in a significant operational cost. As an alternative to landfill disposal, about one-quarter of the fly ash produced in the United States is used for numerous applications, including concrete and cement additives, soil stabilization, flowable fills, grouts, structural fills, and embankments. Fly ash also can be used in the agricultural industry for the construction of feedlot pads as an alternative to natural soil, which tends to remain wet and muddy. Since fly ash is a pozzolanic material, it reacts with a cementing agent such as Portland cement, quicklime, or hydrated lime, to form a high-strength cemented material. Use of compacted fly ash cement-mixtures reduces feed costs as animals do not exert extra energy walking through mud, reduces diseases associated with the presence of the mud, and provides a potentially cost-effective alternative to landfill disposal of fly ash.

With respect to cattle feedlots, the compacted material should achieve a design strength, which is expressed in terms of unconfined compressive strength ($q_u$). Estimates for design $q_u$ are around 40 kPa to support cattle, but may be as high as 200 kPa to support heavy equipment. Unconfined compressive strength cannot be easily measured in situ, but it can be related to dry density ($\rho_d$), the weight of solids divided by the total volume), and water content ($w$, the weight of water divided by the weight of solids), in compacted materials, and $\rho_d$ and $w$ can be measured in situ using a number of different methods. When a fly ash cement-mixture is compacted using a constant compaction effort over a range of $w$, a compaction curve is generated with an optimum water content, $w_{opt}$ corresponding to the peak of the curve (Figure 1). In general, $q_u$ is higher at water contents less than $w_{opt}$ and lower at water contents greater than $w_{opt}$. Unconfined compressive strength also increases with increasing compaction effort. Thus, a $q_u$ acceptance window can be defined.
Predicting the Strength of Compacted Fly Ash Cement-Mixtures, (cont.)

for a given target value using laboratory-derived compaction data, and this acceptance window can be used for construction quality assurance (CQA) testing.

DESCRIPTION OF LABORATORY STUDY

To quantify the relationship between $q_u$, $\rho_y$, and $w$, and to develop a methodology for CQA testing of compacted fly ash cement-mixtures, a laboratory testing program was performed at the University of Kentucky. Class F fly ash was combined with varying amounts of cement and water. The mixtures were compacted using different compaction efforts, and the compacted specimens were strength-tested to perform a parametric study to relate $q_u$, $\rho_y$, and $w$.

Three types of cement were used: portland cement, quicklime, and hydrated lime. Quicklime and hydrated lime are commonly used for soil stabilization. They provide some additional strength when mixed with soil, but their primary function is to reduce soil plasticity, $w$, and shrink-swell potential. Quicklime typically comes as granular material passing a 6.4- or 3.2-mm sieve, and hydrated lime typically comes as a powder. When combined with water, quicklime slakes to form hydrated lime. Hydrated lime combines with silica and alumina in soil to form cementitious calcium silica and calcium aluminum hydrates. Quicklime is advantageous over hydrated lime because it is less dusty and more reactive. It is disadvantageous because the slaking reaction with water is highly exothermic and the excess heat generated is hazardous. Portland cement is most commonly used in Portland cement concrete.

The fly ash was mixed with the three cements to obtain cement contents between 0% and 15%. Compaction was performed using standard and modified Proctor compaction effort (ASTM D698 and D1557), which corresponds to low and high compaction effort, respectively. The material was compacted in a cylindrical mold 10.2 cm in diameter and 11.4 cm in height (Figure 2). For each cement type, cement content and compaction effort, specimens were compacted over a range of $w$ to derive compaction curves. Water content was measured at the time of compaction to represent the initial moisture content of the mixture prior to cement hydration. After compaction, the specimens were extruded from the compaction mold, allowed to cure, and strength tested in a load frame (Figure 3). Values of $q_u$ were superimposed over the standard and modified Proctor compaction curves, and a $q_u$ contour plot was made for each cement type and cement content. In this manner, a method was developed to allow $q_u$ to be estimated using measured values of $\rho_y$ and $w$. Since $\rho_y$ and $w$ can be measured in situ using a number of different field methods, including sand cone, rubber balloon, and nuclear gauge, this approach allows CQA testing to be performed on feedlot pads to confirm that they are built to design specifications.

RESULTS

Results of this study demonstrated that the strength of compacted fly ash cement-mixtures is significantly higher than the strength of fly ash compacted without cement. Strength increased with increasing cement content and compaction effort as expected (Figure 4). Satisfactory strength was achieved for each cement type with cement contents as low as 5%, although the portland cement specimens were about twice as strong as quicklime and hydrated lime specimens.
Predicting the Strength of Compacted Fly Ash Cement-Mixtures, (cont.)

CONCLUSIONS

The use of compacted fly ash cement-mixtures for hay storage, feeding areas, and feedlot has the potential to solve two problems simultaneously. First, use of fly ash for such applications could be an economical alternative to landfill disposal, and utility companies could provide fly ash to farmers at little or no cost if the material was locally available. Second, a feedlot or feeding area surfaced with a compacted fly ash cement-mixture could potentially be superior to a soil feedlot because it would facilitate maintenance and likely improve cattle daily weight gains. This study illustrates the potential for use of compacted fly ash cement-mixtures for feeding and livestock pads by demonstrating its benefits in terms of strength. As a result of this study, the strength of compacted fly ash cement-mixtures can be predicted, and construction specifications and CQA criteria can be developed to optimize the long-term performance of compacted fly ash cement-feedlot pads.

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Actual field strengths of compacted fly ash cement-feedlot pads would most likely be higher than the observed laboratory strengths due to long-term hydration and the subsequent introduction of additional water (rainfall) after compaction. The introduction of extra water during compaction would result in a compacted material with a relatively low density. The approach of compacting near $w_{opt}$ results in a high-density pad, but cement hydration may initially be incomplete. The subsequent introduction of water will allow cement hydration to continue on a long-term basis, which will ultimately result in a denser, stronger, more durable pad.

Results of this study also demonstrated the correlation between $\rho_d$, $w$, and $q_u$. As expected, $q_u$ increased with increasing compaction effort and with decreasing water content. By superimposing and contouring the $q_u$ data over the compaction data, an acceptance window can be defined for any cement type, cement content, and design criterion as illustrated in Figure 5. In this example, a $q_u$ target criterion of 1,000 kPa is selected for compacted fly ash containing 10% Portland cement. By performing in situ $\rho_d$ and $w$ measurements at Points A and B, it would be shown that the material at Point A satisfies the construction criterion, while the material at Point B does not.

Other potential benefits of using compacted fly ash cement-mixtures for feedlot pads include its lightweight nature and low permeability. Fly ash is significantly lighter than soil, so it would be easier and cheaper to transport and handle. The permeability of compacted fly ash cement-pads is relatively low, so there is less opportunity for groundwater contamination and environmental impact. However, low permeability increases surface runoff, so the pads should be constructed with a slight grade and surface liquid control systems to manage the runoff. Research is currently underway at the University of Kentucky Department of Biosystems and Agricultural Engineering to quantify and characterize runoff and drainage from compacted fly ash cement-materials used as beef cattle feeding pads.

Figure 5. Example of $q_u$ data superimposed over compaction data for development of CQA criteria for fly ash mixed with portland cement with a cement content of 10% (contour interval = 200 kPa).
PAREKH RECEIVES DISTINGUISHED MINING ENGINEERING AWARD

Dr. B.K. Parekh, a 30-year veteran of coal preparation research, and longtime researcher at the University of Kentucky Center for Applied Energy Research (CAER), has won a prestigious award. He was recently presented with the Robert H. Richards Award by the American Institute of Mining Engineers (AIME), the parent organization of the Society of Mining Engineering. The Award is given to “recognize achievement in any form which unmistakably furthers the art of mineral beneficiation in any of its branches.” The award was presented to him in February at the 2004 Society of Mining Engineers’ Annual Meeting in Denver, CO.
Thomas Jefferson reported to me a fortnight ago upon his return from Western Pennsylvania that Daniel Boone had found a black liquid seeping from the ground near Fort Duquesne. They discovered that this liquid would burn when lit by a candle. In fact, it is being gathered in crocks and other vessels and transported to Fort Duquesne for use in the lighting of the fort. This oil gives off an unusual black smoke but burns as hot as any wood we know of at this time. The supply of these materials is not known. Therefore, additional methods need to be developed to dig it from the ground wherever it is found and to make this material cleaner to burn.

Another source of energy we are taking for granted is the vast supply of forest we now have. Wood is being used today for about everything from buildings to fuel used in cabin heating and cooking. Again, believe me, this source of fuel is exhaustible and trees are more valuable for building than for burning. Based upon the population growth in this country during the past 10 years and projecting into the future, by 1880 there will not be a tree left standing in this country. Therefore we must develop a new energy resource other than wood.

Coal, which as we all know has been used in England for many years, has recently been found in large supply in the Western part of Virginia and Pennsylvania. Where it is found, it is used extensively, and the most effective use found for coal is in melting iron ore for making steel used in our weaponry. But the largest problem with coal is first of all how do you remove it from the ground in large quantities, and secondly, how do you transport this material to our eastern cities?

Some of our Dutch immigrants tell me that we should take advantage of the wind that blows off of our eastern coast. We could use it to turn a windmill to grind grain or to pump water for our livestock. I understand that this is done in Holland and in some other countries.
HORSE AND BUGGY-POOL

We must investigate all of these possible ways to generate energy so that we can replenish our dwindling supplies of wood and whale oil. Until we can find energy sources which will take the place of these important materials, we should conserve our energy. I suggest, for example, that we extinguish our lights by 9 o’clock at night. We also might store our wood in the damp cellar so that it will not burn so rapidly. Certainly, we should curtail our Sunday afternoon carriage rides and at other times ride to church or to market with our neighbor. This riding of only one or two persons in a rig is a sheer waste of horsepower.

But conserving energy, important as it is, is not the full answer to our energy shortage. This is a young nation full of promise and we need to look for ways to increase our fuel supply in order to expand our economy.

Gentlemen, we have now in our grasp the makings for the discovery of a host of new sources and new uses for energy which will strengthen the growth of this country and possibly even provide exports to other countries.

But for us to take advantage of these opportunities, we must establish a national energy program which is supported by funds from this Congress. With the aid of Dr. Franklin, Mr. Jefferson, and several others, we have prepared a program plan for energy development which calls for an appropriation from Congress of $100,000 annually over the next 5 years. With this large sum we can indeed develop our energy resources within our continental land boundaries, so that never again will we be at the mercy of pirates or suffer from the diminishing supply of whales.

I submit this plan for your consideration and adoption. Please act with dispatch for we do not want the lights of America ever to go out, but to shine always as bright as the brightest star in the heavens.

This tongue-in-cheek editorial was actually written in the not-so-distant 1970s by Dr. Dick Wolfe, then the Program Manager with the U. S. Energy Research and Development Administration (ERDA) in Washington, D.C, the fore runner to the Department of Energy. Dr. Wolfe is currently Director at the Center for Applied Science at Lees-McRae College in North Carolina and serves as a consultant to CAER.