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Calcium Bentonite Slag Admix for Waste Containment

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Introduction

Encapsulation is probably the most commonly used technique for containment of old waste disposal sites and sometimes for new landfills. Active waste disposal facilities that have no liners and/or leachate collection/treatment system installed, by and large, use vertical barriers. Slurry walls act as vertical barriers. They have a history of satisfactory performance in fresh water environment, which led to their use around waste disposal sites to prevent lateral migration of liquid pollutants into the surrounding groundwater. A leachate collection system is often installed on the inward side of the barrier. Leachate level within the containment is kept below the outside groundwater level. This ensures an inward flow of groundwater and thus prevents migration of pollutants outside of the walls. There are two major types of slurry walls, a soil-bentonite and a cement-bentonite wall. Primary consideration in the design of such walls is hydraulic conductivity. However, shear strength may not be ignored as the wall must resist lateral pressure from adjacent soils.

Soil-bentonite Wall

A soil-bentonite wall is constructed in two stages. In the first stage a trench is excavated under bentonite slurry, which maintains the stability of the trench. This is followed by replacing the slurry with a soil-sodium bentonite mix especially designed for the conditions prevalent in the field. The construction process requires a large working space. Being a two-step operation it takes longer to construct a soil-bentonite wall. Such walls are

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more commonly used as they exhibit a hydraulic conductivity of less than 10^{-9} m/s, which in most specifications is the maximum permissible value. Experience has shown that soil-sodium bentonite walls, when used for waste containment, have a relatively short useful lifespan.

Cement-bentonite Wall

In a cement-bentonite slurry wall the vertical trench is excavated under a cement-sodium bentonite slurry instead of bentonite alone. After the trench is complete the slurry is left in place which, in time, cures and forms the impervious barrier. Thus the construction process of a cement bentonite wall is a single stage operation. It has a shorter construction period and it requires less working space than a soil bentonite wall. Where adequate amount of soil is economically unavailable, a cement sodium-bentonite wall is a more cost-effective choice. However, such a wall has a somewhat higher hydraulic conductivity i.e., of the order of 10^{-8} m/s. As the result, cement-bentonite walls are not used in waste containment structures.

The low value of hydraulic conductivity of both types of these walls is due to the presence of sodium bentonite, which exhibits high swelling. Consequently, sodium bentonite has been the choice material for slurry walls used in waste containment structures. Field and laboratory data indicate that in the presence of organic chemicals, commonly present in waste deposits, hydraulic conductivity of mixes containing sodium bentonite increases (D'Appolonia, 1980; Ryan, 1987; Grube et al., 1987). Sodium is an externally adsorbed ion in bentonite. An externally adsorbed ion can be replaced by other ions with greater replacing power. For example, sodium ions can be replaced by organics. The properties of a clay which has undergone an ionic exchange can diverge substantially from the original clay. The soils which realize their low hydraulic conductivity from their high swelling potential due to an abundance of monovalent ions are most likely to exhibit increased hydraulic conductivity when these ions are replaced by other ions, resulting in considerable reduction in their swelling potential.

Alternative Materials

In this study the feasibility of using calcium-bentonite, which is more stable than sodium bentonite, and slag in vertical cutoff walls is presented. Calcium bentonite was obtained from two sources, one from American Colloid Co., Arlington Heights, Illinois, and the other from Greece (G) marketed by IKO Industriekohle GmbH & Co, Marl, Germany. Cement was a Type A Portland Cement from Lehigh Cement Co. Slag is marketed as NewCem by Blue Circle Atlantic, Atlanta, Georgia. It consists of calcium, aluminum and magnesium silicates and conforms to ASTM C 989.

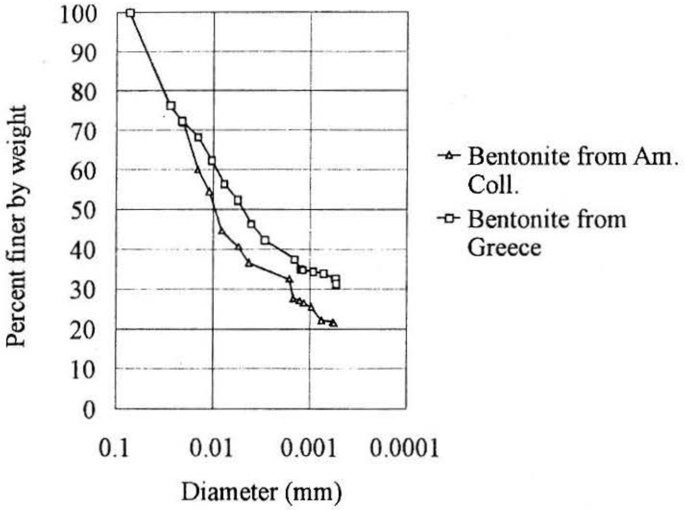

FIGURE 1 : Grain-size Distribution Curves for Two Calcium Bentonites

Grain Size Characteristics

Grain size distribution curves based on ASTM D 422 for the two types of Calcium-Bentonites are given in Fig.1. Both samples passed completely through a No. 200 sieve and have similar grain size characteristics.

Effect of pH on Swelling Potential

Low hydraulic conductivity exhibited by the mixes containing sodium bentonite is due to the high swelling potential of sodium bentonite. To maintain the integrity of slurry, it is recommended that the pH of the slurry be maintained around eight (Xanthakos, 1979) during construction. As shown in Fig.2 for pH values of 7 to 10 the swelling capacity is very high for Na bentonite (Reuter and Meseck, 1986). For pH values of 6 or less, as well as, pH values greater than 10 the swelling potential of sodium-bentonite drops substantially. Calcium bentonites on the other hand, show smaller drop in swelling potential for pH values (ASTM D 4972) less than 7 and none to some increase in swelling potential for pH more than 7. Since there is no control on the pH that may prevail at any time in a waste deposit, properties of calcium bentonite would not be affected by pH changes. To achieve the desired hydraulic conductivity for a slurry wall about three to six percent of sodium bentonite is added to the backfill mix (Xanthakos, 1979). Note that swelling potential of sodium bentonite is more than four to five times that of calcium bentonite. To achieve an equivalent reduction in hydraulic conductivity of a mix more calcium bentonite will be needed, as much as four to six times that of sodium bentonite.

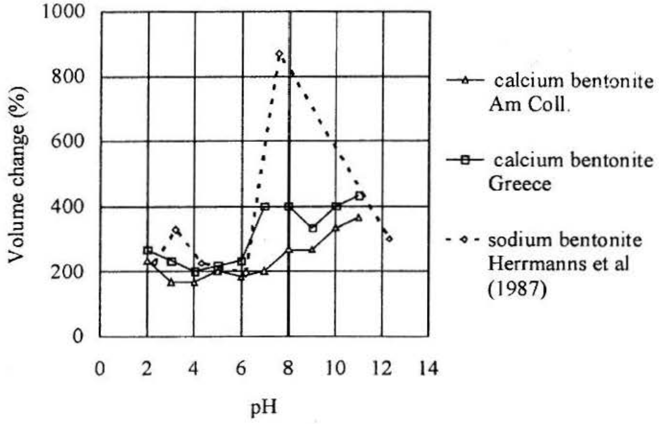

FIGURE 2 : pH Effect on Swelling of Calcium and Sodium Bentonites

TABLE 1 : Mix Proportions in Percent

Source	Bentonite (%)	Cement (%)	Slag (%)	Water (%)	Sample ID
American Colloid	12	15	–	73	12A+15C
	12	7.5	7.5	73	12A+7C+7S
	18	5	10	67	18A+5C+10S
Greece	15	15	–	70	15G+15C
	15	7.5	7.5	70	15G+7C+7S

TABLE 2 : Permeant Concentrations

Permeant	Concentration
Anilin	5000ppm
Phenol	5000ppm
TCE	Concentrated
Leachate	Municipal Landfill

Soil Mixes

Five different trial mixes were used. The proportions of various mixes are shown in Table 1. Table 2 shows the permeants and their concentrations for hydraulic conductivity tests.

Hydraulic Conductivity of Specimens

Calcium bentonite was mixed with water and left overnight for hydration. Cement and slag were added to the hydrated bentonite, as needed, and mixed in a mechanical blender. The mixture was then poured into cylindrical molds about 70 mm in diameter. The height of the specimens ranged between 25 mm and 60 mm. The molds containing the mixes were stored in a humid room for curing. After seven days the specimen were extruded from the molds, wrapped in wet paper towels, sealed in zip-lock bags, and left in the humid room till used.

Triaxial Test Specimens

After mixing, the slurry was vacuumed for 10 minutes and poured into cylindrical molds 36 mm in diameter and 60 mm in height. The molds containing the slurry were wrapped in wet paper towels and kept sealed in reusable storage bags for further curing; paper towels were always kept wet. After 3 days, the specimens were extruded from the molds, wrapped again with wet paper towels and sealed in storage bags. Compression tests were performed after curing periods of 7 days, 14 days, and 28 days. The tests were conducted in an air-conditioned laboratory at a room temperature of ± 22°C.

Testing Methods

Hydraulic Conductivity Tests

Hydraulic conductivity tests were conducted in flexible wall permeameter (ASTM D 5084). The specimens were wrapped in Saran-wrap (plastic wrap) to protect the rubber membranes from the effect of organic chemicals. The samples were saturated using back-pressure ranging from 290 kPa to 345 kPa. A pore pressure parameter B of 0.95 or greater was achieved for all specimens. These values were maintained for 24 hours before starting a hydraulic conductivity test. Hydraulic gradient was applied by increasing pressure at the top and reducing it at the bottom. The hydraulic gradient ranged from 25 to 34, with most tests being conducted at a gradient of 30 (Tirumala, 1989).

Triaxial Tests

Consolidated undrained triaxial tests were conducted using ASTM D 4767 method. For triaxial test specimens constituted with American Colloid calcium bentonite effective consolidation pressure ranged from 100 kPa to 117 kPa and back-pressure from 290 kPa to 350 kPa. For the mixes containing bentonite from Greece, the effective consolidation pressure was 50 kPa and back-pressure was 450 kPa (So, 1991).

Results and Discussion

Hydraulic Conductivity Tests

Hydraulic conductivity of various trial mixes was first determined using water. Results of these tests are shown in Fig.3. Specimens with 12 percent calcium bentonite from American Colloid (specimens 12A + 15C and 12A + 7C + 7S) and different proportions of cement and slag, showed hydraulic conductivity greater than 10^{-9} m/s. Note that replacement of 50 percent cement with equal amount of slag (specimen 12A + 7C + 7S) decreased hydraulic conductivity by one order of magnitude when compared with specimen 12A + 15C. These hydraulic conductivity values are greater than 10^{-9} m/s. Similarly, looking at the other calcium bentonite from Greece, specimen 15G + 15C, showed a hydraulic conductivity value of 10^{-8} m/s, which is also too high. None of these mixes was satisfactory as they had hydraulic conductivity greater than 10^{-9} m/s.

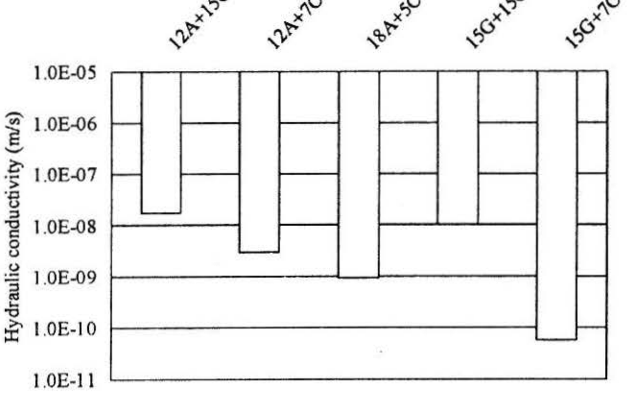

FIGURE 3 : Hydraulic Conductivity of Various Mixes with Water

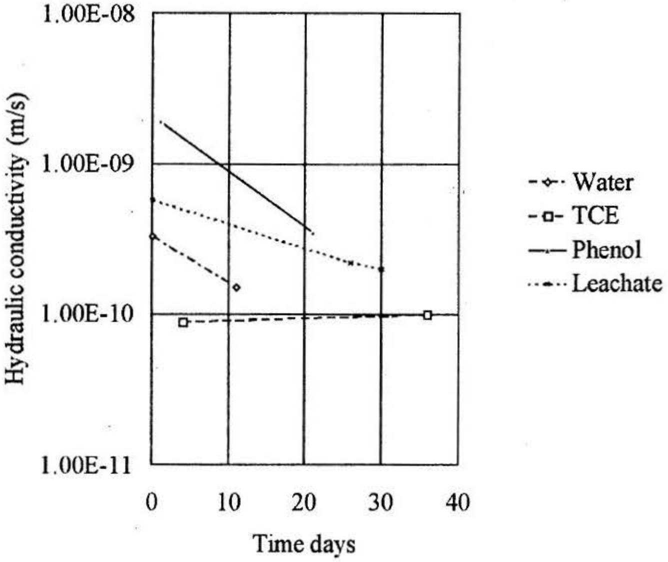

FIGURE 4 : Hydraulic Conductivity for Samples 18A+5C+10S with Permeants

For American Colloid the amount of bentonite was increased to 18 percent and the proportion of slag was increased to 10 percent. This change yielded an acceptable value of hydraulic conductivity, i.e., $\leq 10^{-9}$ m/s. In the case of bentonite from Greece, half the cement was replaced with slag. The test specimen 15G + 7C + 7S showed 3 orders of magnitude decrease in value of hydraulic conductivity. The rest of the specimens were prepared with these proportions. The mixes that resulted in hydraulic conductivity 10^{-9} m/s or less were then tested with organic permeants.

Figure 4 shows that the hydraulic conductivity decreased with all the permeants as the time went by, except with TCE where it shows a very slight increase. For calcium bentonite from Greece, as shown in Fig.5, the hydraulic conductivity also decreases with time for water, aniline, and phenol. Thus the data presented here indicate that containment structures prepared with calcium bentonite will not experience an increase in hydraulic conductivity with time compared to those made with sodium bentonite (Hermanns et al., 1987).

Triaxial Test Results

Stress strain data shown in Fig.6 indicate the peak stress to occur at relatively low strain of 1%. Beyond this strain there is a moderately low

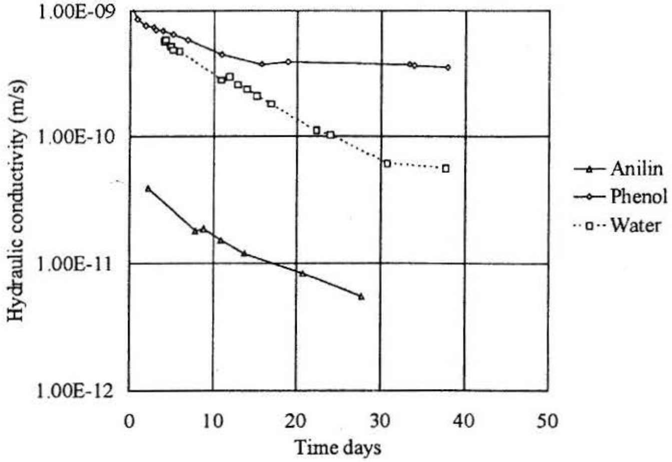

FIGURE 5 : Hydraulic conductivity for Mix with Calcium Bentonite from Greece

drop in stress. All test specimens for this investigation underwent a strain of 20 percent without showing complete failure. Pore water pressure was positive initially but then turned negative at a strain of about 7% as seen in Fig.6.

Effect of Curing Period on Shear Strength

The length of curing period had a considerable effect on the peak stress as seen in Fig.7. As we go from seven day curing period to fourteen

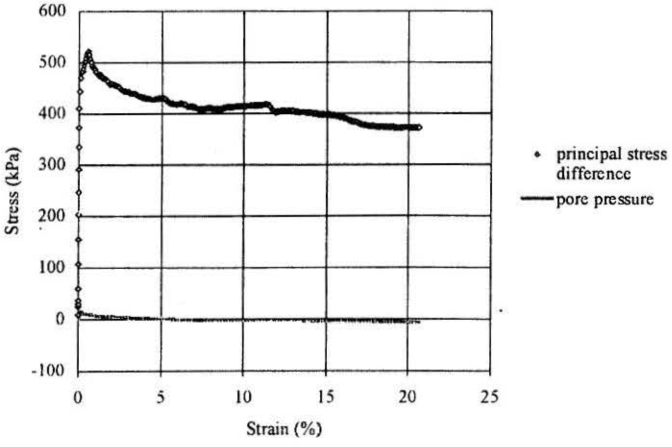

FIGURE 6 : Triaxial Compression Test on Specimen Mix 18A+5C+10S

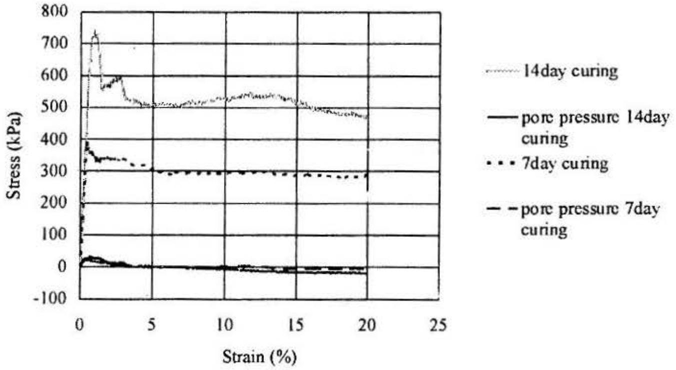

FIGURE 7 : Curing Period Effect on Sample Mix 15G+7C+7S

day curing period, the peak stress increased from 400 kPa to 700 kPa and the strain at which peak stress occurred increased from ½ percent to 1 percent. There was no sudden failure after the test specimens attained their peak shear stress. Pore pressure changes were not significantly different as seen in Fig.7. The response of stress strain curves and pore water pressure from the two different bentonite mixes is very similar.

The effect of curing period on strain at peak stress is shown in Fig.8. The strain at peak stress appears to increase with increasing age, though

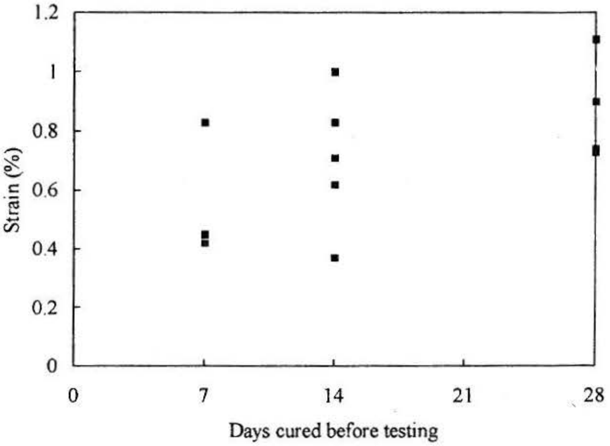

FIGURE 8 : Strain at Peak Stress for Different Curing Periods, all Specimens Designated 15G+7C+7S

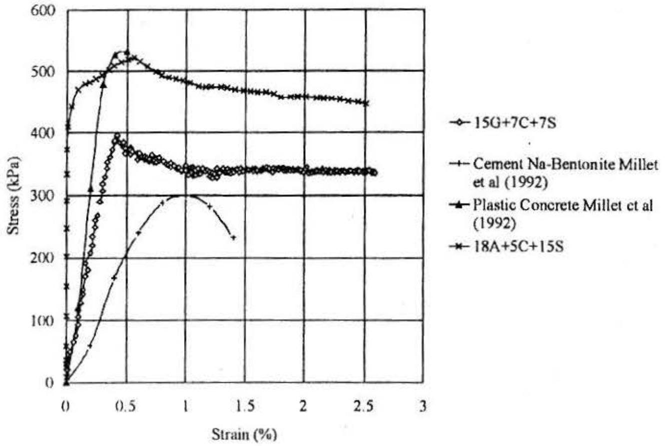

FIGURE 9 : Comparative Results from Triaxial Compression Tests

there is considerable scatter in data. If in the field a crack does materialize after some time, the peak stress and the strain at peak stress will be greater than those observed in the laboratory tests as both show an increase with curing time. Both these factors will have a positive effect on the integrity and performance of a wall.

For comparison purpose data from plastic concrete and sodium bentonite cement mix, which have also been considered for use in slurry walls (Millet et al., 1992), are presented in Fig.9. Stress strain data for plastic concrete indicate that failure occurred suddenly at a low strain. The peak shear stress for calcium bentonites also occurs at low strain, but these specimens do not fail suddenly. They continue to deform with decreasing shearing stress. All the tests were carried on to a strain of 20 percent or more without showing any sudden drop in shear stress. The shear stress for a Cement-Na-Bentonite mix also appears to drop off more rapidly than that of the two mixes used here. The strength values for the two calcium bentonite mixes are similar to plastic concrete mix but higher than that of Cement-Na-Bentonite.

Conclusions

- Hydraulic conductivity values of less than 10^{-9} m/s were obtained with 15 percent calcium bentonite from Greece and 18 percent calcium bentonite from American Colloid when used in combination with cement and slag.

- Partial replacement of cement with slag reduced hydraulic conductivity by 1 to 3 orders of magnitudes.

- Hydraulic conductivity decreased with time for 5000 ppm aniline and phenol, concentrated TCE, and a leachate from a municipal solid waste.

- Peak shear stress during consolidated undrained triaxial compression test was comparable to that of plastic concrete.

- Unlike plastic concrete the test specimens did not fail suddenly during compression tests. After reaching peak shear stress they continued to deform even at strain as large as twenty percent.

- Calcium bentonite along with slag may be a good alternative to sodium bentonite in cement-bentonite slurry wall for waste containment.

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