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Free Swell Characteristics of PCC Bottom Ash-Bentonite Mixtures with Curing for Use as Fill or Liner Material

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Bottom ash is a coal combustion product (CCP) obtained from burning of pulverized coal to produce electricity. Most of the bottom ash from pulverized coal combustion (PCC) plants is disposed of in landfills and/or ash ponds. Over the last decade, there has been increased attention aimed toward the use of PCC bottom ash in geotechnical applications. The particle size distribution of pulverized coal combustion (PCC) bottom ash is similar to that of natural sand. Natural sand is commonly used in the construction industry in place of cohesive soils by adding admixtures to amend its properties. Several studies have been completed to determine the properties of bottom ash amended with bentonite. However, due to significant volume change characteristics of bentonite, soils or similar granular materials amended with it need to be evaluated for their swelling behavior. In addition, studies on bottom ash-bentonite mixtures have shown that strength and stiffness characteristics of these mixtures change significantly with curing. Therefore, in order to evaluate the use of bottom ash as a fill or landfill liner material, this study was initiated to investigate the effect of curing and moisture content on the swelling characteristics of pulverized coal combustion bottom ash amended with bentonite. Bottom ash specimens containing 15 and 20 percent bentonite and prepared at 14, 16 and 18 percent initial moisture content were tested in this investigation. Results presented show the swelling characteristics of bottom ash-bentonite mixtures with curing age up to 60 days.

Keywords Bentonite, bottom ash, coal combustion, curing, fill, landfill liners, swelling

Introduction

The use of coal in power generating plants around the world results in the production of an overwhelming amount of coal combustion products (CCPs). These products must be disposed of in an acceptable and environmentally safe manner. Currently, a large portion of these CCPs are disposed of in landfills and/or ash ponds. In the early 1990s, only 10% of the total CCPs produced in the United States were being used in various applications (Dube, 1994). The utilization of CCPs increased to approximately 29 percent in the year 2000 and to 33 percent in the year 2001 (Kalyoncu, 2003; Kelly and Kalyoncu, 2002). According to a report released on the production and usage of CCPs, ACAA (2003) estimates a total 2002 CCP production of 128.7 million tons as compared to 117.9 million tons in 2001. Overall CCP utilization for 2002 is estimated at 45.5 million tons, or 35.4 percent of the

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total production compared to 37.1 million tons or 31.5 percent of total production in 2001. In 2002, a total of 19.8 million tons of bottom ash was produced and 7.7 million tons, i.e. 38.8 percent was used compared to 5.7 million tons utilized in 2001 (ACAA, 2003). Although utilization of CCP increases from 10 percent in the early 1990s to over 35 percent in 2002, a vast amount of bottom ash is still being hauled to landfills or sluiced to ash ponds. Because of strict environmental regulations in place and limited availability of land to build landfills and ash ponds, there is immediate need to develop new, environmentally safe, and cost-effective applications, of CCPs. Currently, most of the CCPs used are in the construction applications, including use in grout, concrete, road base, sub base material, and mining applications. Several case histories of utilization of coal combustion products in construction projects are available (ACAA, 1998; GAI, 1988; Golden, 1986; Korcak, 1998; Kumar and Stewart, 2003a,b; Lovell *et al.*, 1997; Naik *et al.*, 1997; Schroeder, 1994; Seals *et al.*, 1972; Tikalsky and Carrasquillo, 1989).

Pulverized coal combustion bottom ash is a dark gray, granular, and porous material that has particle sizes ranging from silts and clays sizes to fine gravel. Natural sand is commonly used in the construction industry in place of cohesive soils by adding admixtures to amend its properties. Most scientists and researchers have come to the conclusion that bottom ash from PCC power plants displays physical properties similar to that of natural sands. Therefore, some researchers have studied the possibility of use of PCC bottom ash in various construction applications, e.g., fill and landfill liners, after modifying its properties by mixing it with various admixtures, e.g., Das *et al.* (1978), Huang and Lovell (1990 and 1993), Kayabali and Bulus (2000), Kumar *et al.* (2004), Kumar and Stewart (20030), Kumar and Vaddu (2004a,b), and Seals (1972). In this study, swelling characteristics of PCC bottom ash amended with sodium bentonite have been studied. Sodium bentonite is a common type of clay frequently used to modify soil properties. Sodium bentonite shows a very high volume change potential with the change in its moisture content. Aluminum silicate in bentonite is considered as the primary cause of the significant volume change potential of bentonite. This property of bentonite is considered a blessing for some applications, whereas it can be detrimental in several others. When soils to be used as fill or landfill liners are modified with bentonite, significant amount of volume change of the fill or landfill liner may be detrimental. Therefore, soils or similar materials amended with bentonite should be evaluated for their volume change potential.

Some studies involving bottom ash-bentonite mixtures have addressed the issue of the effects of volume change property of bentonite on the overall swelling behavior of bottom ash-bentonite mixtures. A recent study conducted by Kumar and Vaddu (2004a) has shown that strength and stiffness characteristics of bottom ash-bentonite mixtures change significantly with the curing age of the mixtures. Therefore, the aim of this study was to evaluate the effects of curing on the swelling characteristics of bottom ash-bentonite mixtures so that the engineers can make informed decisions about their use for fill and landfill liner purposes. Bottom ash-bentonite mixtures containing 14, 16 and 18 percent initial moisture content, 15 and 20 percent bentonite, and cured for up to 60 days, were tested in this study. Free swell response of the mixtures was studied by conducted swell potential tests. Results presented show a significant effect of initial moisture content and curing time on the swelling characteristics of the bottom ash-bentonite mixtures.

Specimen Preparation

The bottom ash used in this study was air dried and sieved through U.S. Standard No. 40 sieve. The bottom ash was obtained from a coal burning power generating plant in

Springfield, Illinois, which burns coal from the Illinois basin. The bentonite was obtained from Central Mine Equipment Company, St. Louis, Missouri. Sodium bentonite is also commonly referred to as gold gel in the construction industry. Bentonite is naturally occurring hydrated aluminum silicate, having a chemical formula Na $Al_6(Si_4O_{10})_3(OH)_6$, formed in the course of several million years through the weathering of volcanic ash. It has negligible solubility in water, and is highly plastic and highly colloidal expansive clay. The bentonite used was sodium bentonite with a liquid limit of 550 and plastic limit of 55.

The specimens were prepared with 15 and 20 percent bentonite by weight of the total weight of the dry mixture. The specimens were prepared at three different initial moisture contents, i.e., 14, 16 and 18 percent, and the dry unit weight of the specimens was targeted at 100 pounds per cubic foot (pcf). All specimens at a specified initial moisture content, i.e., 14, 16, or 18 percent, were prepared from the same batch of mixture to obtain consistent specimens. For mixing all the ingredients, the exact amount of bentonite and bottom ash needed were weighed out first and placed in a large pan. They were then mixed together using two large spatulas to obtain uniform mixture free of large lumps. The required amount of water was then gradually added and mixed thoroughly. The mixture was covered with plastic to avoid any moisture loss and allowed to sit overnight to ensure uniform distribution of moisture in the mixture.

The following day the soil was mixed again slightly and specimen preparation for swell test was initiated. In order to obtain 3 specimens for free swell tests (2.5 inch diameter and approximately 0.7 inch high), it was decided to first compact the mixtures to obtain a 2.8 inch diameter and 5.8 inch high cylinder having a targeted unit weight of 100 pcf, and then the specimens for swell tests were cut out from the compacted cylinder. Therefore, the amount of wet mixture needed to obtain a cylinder of 2.8 inch diameter and 5.8 in high having a unit weight of 100 pcf, was weighed and the compaction was accomplished in five layers. The height of each layer was carefully monitored using a digital caliper to obtain a cylinder with uniform unit weight. Each compacted cylinder of bottom ash-bentonite mixture was cut into three parts to prepare three specimens.

The specimens to be tested after curing were carefully wrapped in plastic and sealed in three ziplock bags, and placed in a tub of water. The reason for placing the specimens in water was to ensure curing of specimens at a constant temperature. Since water was not allowed to flow in or out of the specimens, the curing took place at a constant moisture content, i.e., moisture content of the specimens remained constant during curing. Specimens in the water tub were checked regularly to make sure water did not enter into the specimens. After a specified period of curing, a set of three specimens was taken out of the water and final preparation of specimens in consolidation rings for the swell test was initiated. As discussed previously, one set of the specimens was tested immediately after specimen preparation, i.e. no curing, and other sets were tested after 7, 28, and 60 days of curing.

Testing Procedure

All tests were preformed in general accordance with the procedure outlined in the American Society for Testing and Materials (ASTM D-4546-96). The consolidation ring having approximate inner diameter of 2.5 inches and height of approximately 0.7 inches was pushed through each piece and the extra material was carefully trimmed in accordance with the ASTM Test Method D 2435-96 to match the height of the consolidation ring. Extreme care was taken during specimen preparation to avoid any gap between the ring and the specimen. Each ring was weighed to cross check the unit weight. Trimmings were used to

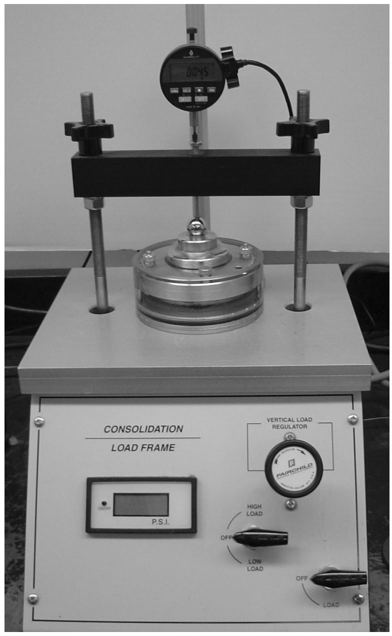

Figure 1. Free Swell Test in Progress.

obtain the moisture content data of the specimens before start of the test. Once the specimen was trimmed and weighed it was wrapped in plastic again to ensure that no moisture was lost while the other specimens were trimmed. When all three specimens were completed they were removed from the plastic and placed in the consolidation apparatus as shown in Figure 1. After setting the swell measurement digital dial gage to zero, the specimens were inundated with water and were allowed to swell freely. Free swell measurements were made at time intervals similar to that used for consolidation test. Each test was allowed to run for at least 48 hours.

Results and Discussion

As discussed in the previous sections, the objective of this study was to understand the effect of curing age on the swelling characteristics of bottom ash amended with bentonite so that engineers can make informed decisions for its use in the construction of fill and landfill liners. In order to accomplish the objects of the study, specimens with 15 and 20 percent bentonite and prepared at 14, 16 and 18 percent initial moisture content were tested in this study. The specimens were tested at 0, 7, 28, and 60 days of curing.

Figure 2 presents the free swell response with time for specimens containing 15 percent bentonite, prepared at an initial moisture content of 14 percent, and cured for 0 (no curing), 7, 28, and 60 days. Similar response for bottom ash specimens with 15 percent bentonite and initial moisture contents of 16 and 18 percent are shown in Figures 3 and 4, respectively. The time scale on all these figures is represented as a log scale. Figures 2 through 4 show that within first 10 minutes of inundating all the specimens, swelling was marginal. But after 10 minutes, swelling increased rapidly until about 1000 minutes, when it slowed down again. All the specimens were allowed to swell until the increase in free swell with time became marginal. The percent free well was calculated by taking the ratio of free swell at

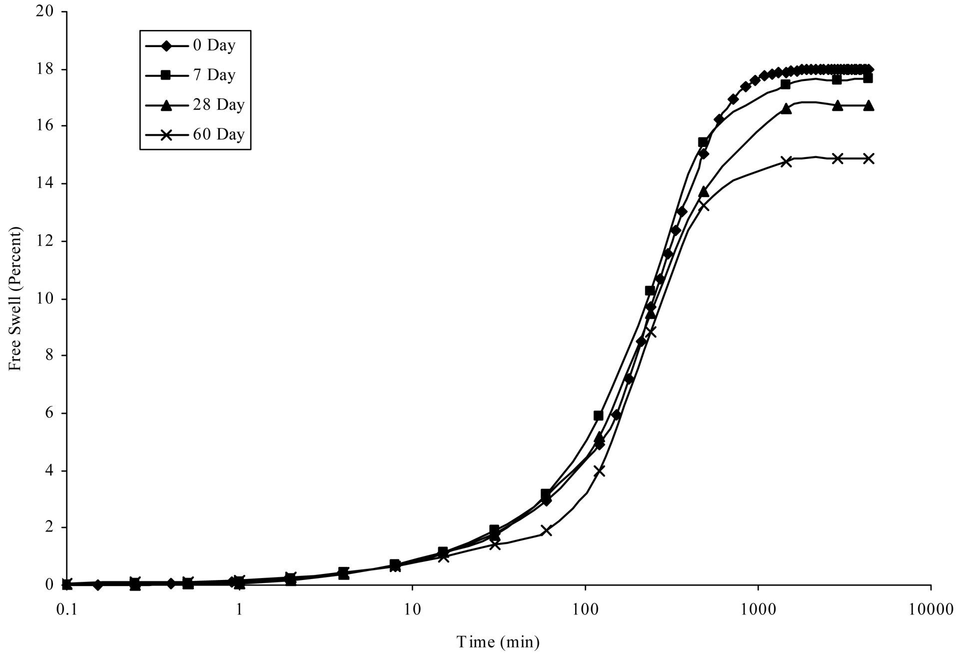

Figure 2. Free Swell versus Time for 14% Initial Moisture Content (IMC) and 20% Bentonite at each Curing Period.

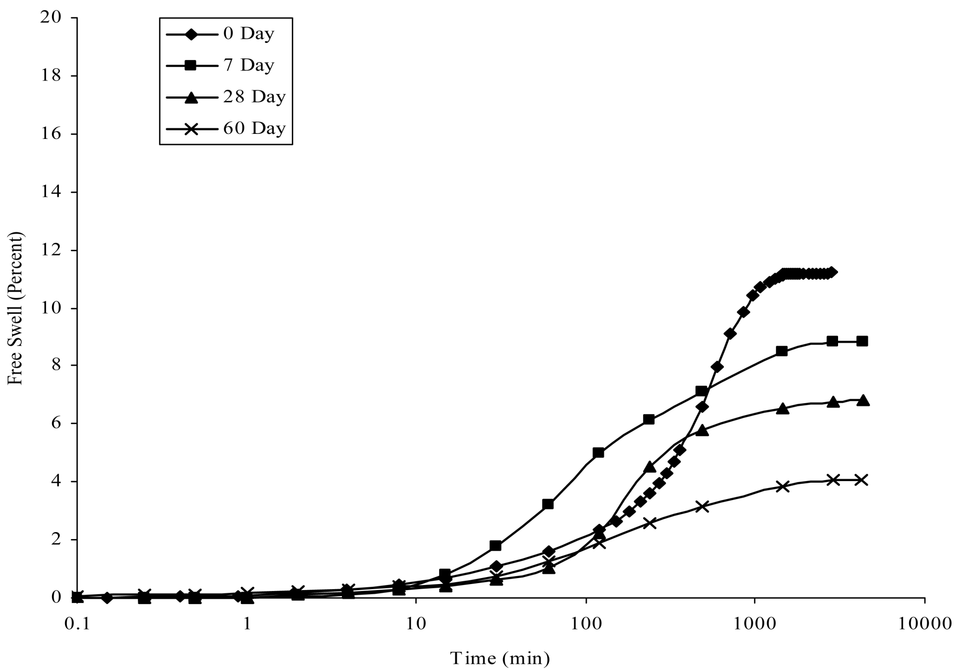

Figure 3. Free Swell versus Time for 16% Initial Moisture Content (IMC) and 20% Bentonite at each Curing Period.

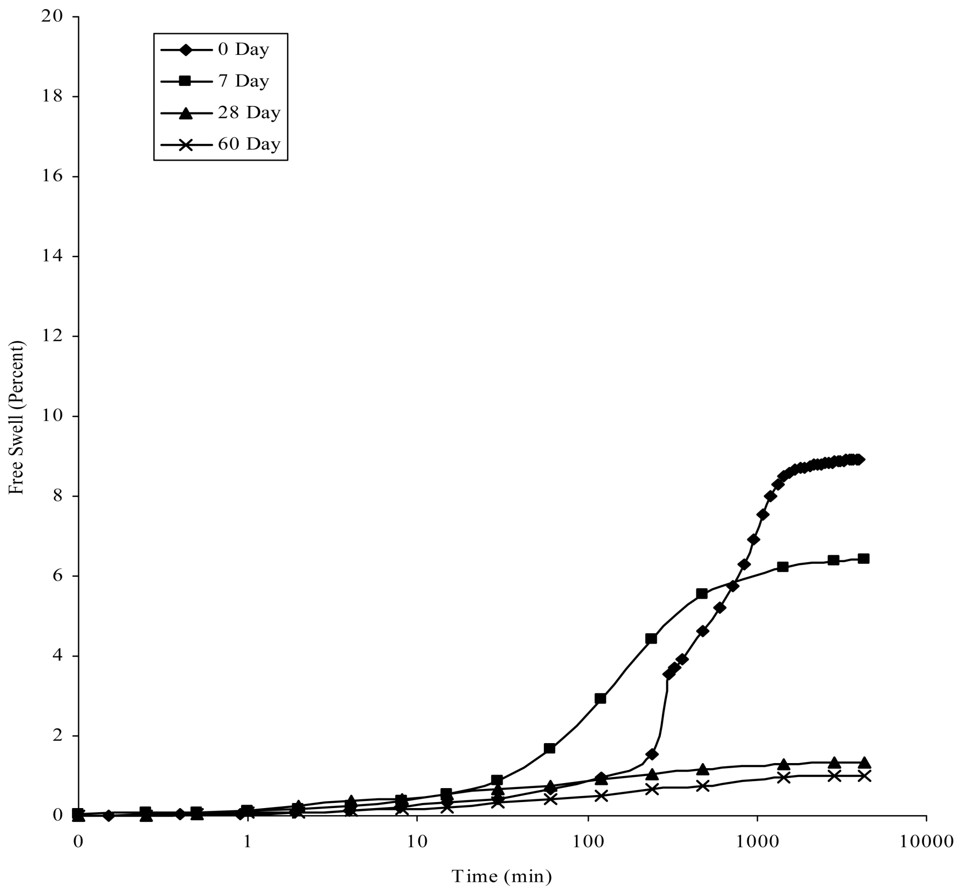

Figure 4. Free Swell versus Time for 18% Initial Moisture Content (IMC) and 20% Bentonite at each Curing Period.

any time and the specimen height before starting the test. The largest value of the percent free swell was noted as the maximum free swell.

Figures 2 through 4 also show that the swell potential decreased with the increase in the curing period. The maximum percent free swell from specimens prepared at an initial moisture content of 14 percent was observed to be 18, 17.7, 16.7 and 14.9 at 0, 7, 28 and 60 days of curing, respectively. Similarly, the maximum percent free swell from specimens prepared at an initial moisture content of 16 percent was observed to be 11.2, 8.8, 6.8, and 4.1 at 0, 7, 28 and 60 days of curing, respectively. For specimens prepared at 18 percent initial moisture content, the maximum percent free swell was observed to 8.9, 6.4, 1.3 and 1.0 at 0, 7, 28 and 60 days of curing, respectively. Similar results were observed from specimens with 15 percent bentonite which are not presented here.

In order to further study the above observations, the maximum free swell from specimens with 20 percent bentonite, prepared at various initial moisture contents, and curing for 0, 7, 28, and 60 days was plotted on a common axis as shown in Figure 5. The results presented in Figure 5 show that the free swell decreased as the initial moisture content of the specimens increased, irrespective of how long the specimens were cured. Figure 5 also shows that the percent free swell decreased with the curing age irrespective of the initial

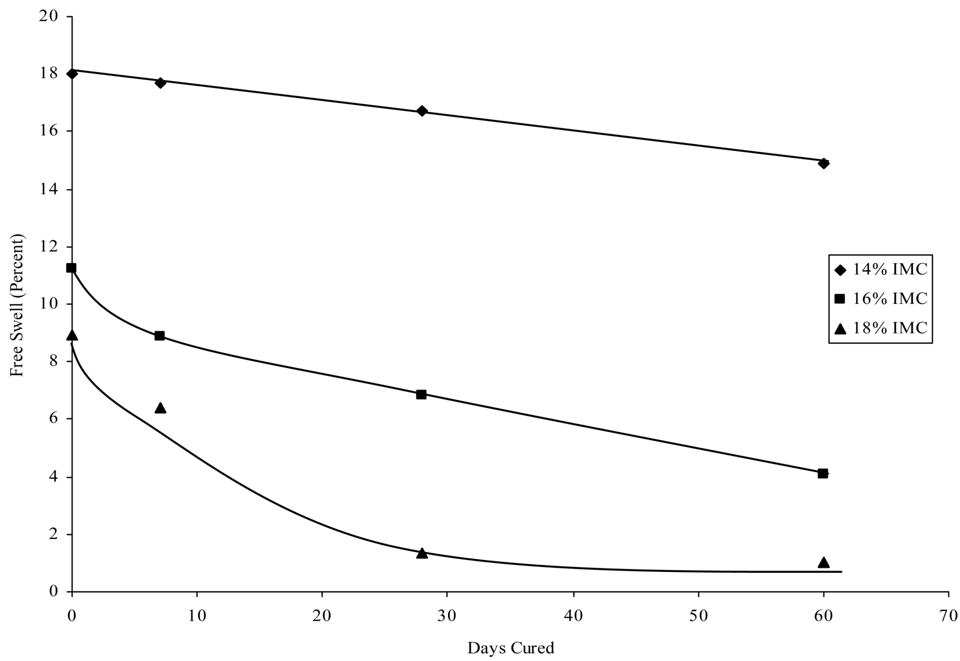

Figure 5. Maximum Free Swell Response with Curing Period for 20% Bentonite Specimens.

moisture content of the specimens. However, the decrease in free swell with curing age was observed to be almost linear for specimens made with 14 percent initial moisture content, whereas in the free swell response with curing age for specimens with 16 and 18 percent initial moisture contents, the decrease was observed to be nonlinear. Results obtained from specimens made with 18 percent initial moisture content indicate insignificant change in free swell after 28 days of curing, whereas specimens made with 14 and 16 percent initial moisture contents indicate that curing beyond 60 days is likely to result in further decrease in the free swell.

Figure 6 presents results similar to those presented in Figure 5, but for bentonite content of 15 percent. Similar to the observations made from the results of 20 percent bentonite specimens, results presented in Figure 6 show that free swell decreased with the increase in the curing age. However, response from all specimens was observed to be nonlinear. Results from 15 percent bentonite specimens show that decrease in percent free swell beyond 28 days of curing is much less compared to that before 28 days. Unlike the results from 20 percent bentonite specimens, results from 15 percent bentonite specimens indicate that decrease in free swell beyond 60 days is likely to be minimal.

Comparison of Figures 5 and 6 shows that free swell in some specimens with 15 percent bentonite and initial moisture content of 18 percent is slightly higher than that in specimens with 20 percent bentonite. It is important to note that although every effort was made to prepare specimens at the targeted initial moisture content, the moisture content of some of the specimens with 20 percent bentonite was approximately a percent higher than that of specimens having 15 percent bentonite, which resulted in lower swelling of the specimens with 20 percent bentonite.

Figure 7 shows the free swell response of 15 and 20 percent bentonite specimens with initial moisture content after 60 days of curing. The results presented show that free

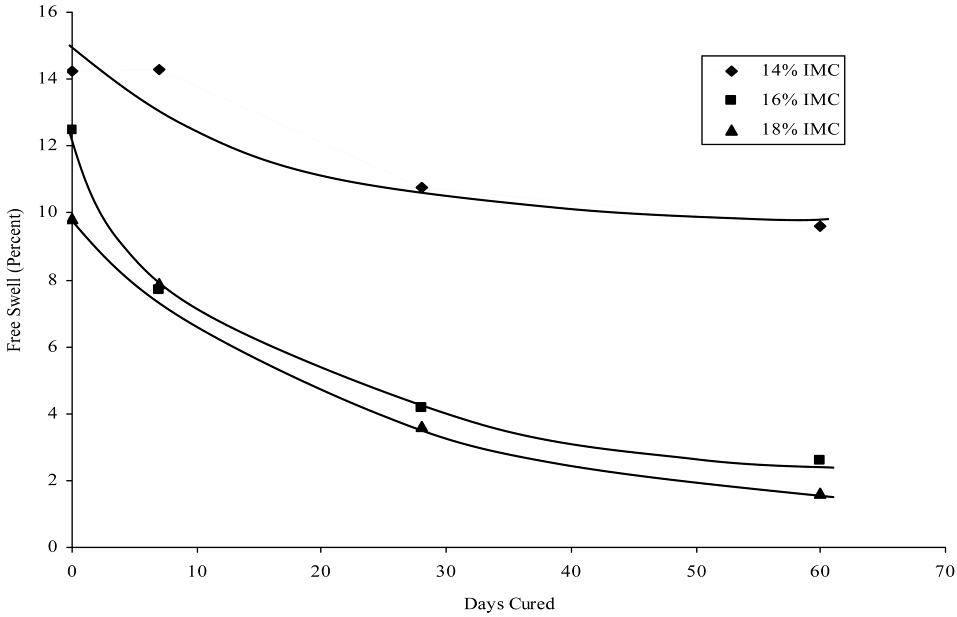

Figure 6. Maximum Free Swell Response with Curing Period for 15% Bentonite Specimens.

swell was much higher in the specimens containing 20 percent bentonite, which should be expected since presence of bentonite in the bottom ash-bentonite mixtures is the primary cause of swell potential. Figure 7 also clearly shows that the initial moisture content of the specimens has significant effect on the free swell potential. The percent free swell

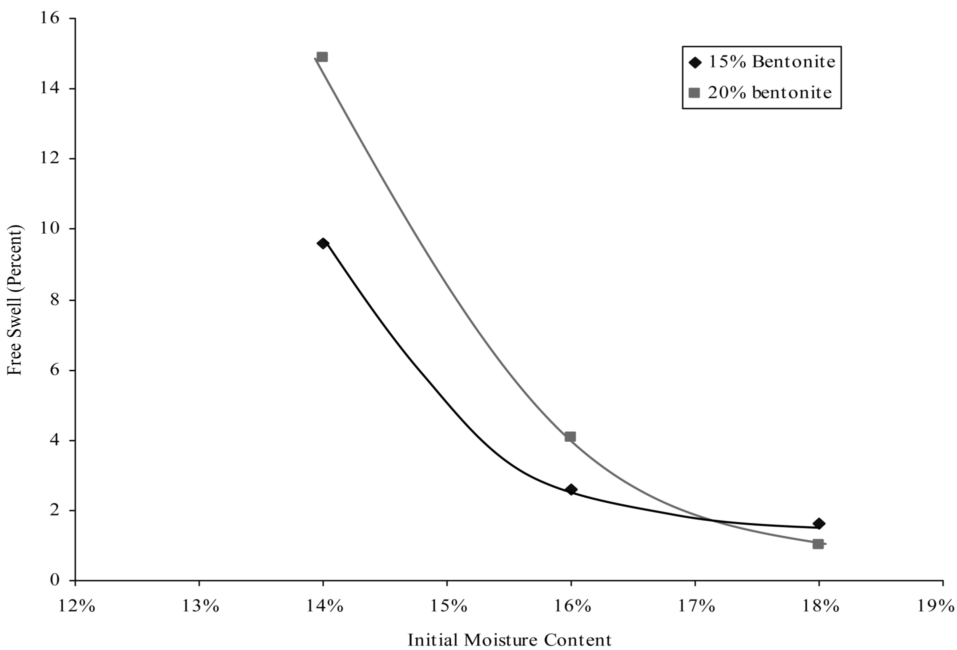

Figure 7. Maximum Free Swell Response with Initial Moisture Content after 60 Days of Curing.

decreased significantly when the initial moisture content increased from 14 to 16 percent. Beyond 16 percent moisture content, the change in the free swell was observed to be much less, primarily because of lower affinity for water. It is also interesting to note that after 60 days of curing, the free swell of 15 percent bentonite specimens is approximately the same as that from 20 percent bentonite specimens.

The results presented above are significantly important for utilization of PCC bottom ash in fill and landfill liners. It is clear from the results that the placement of the mixture at a higher initial moisture content would result in lower swelling potential. In addition, the results presented clearly show that the swelling potential of the bottom ash-bentonite mixture reduces with curing age. These observations would help the engineers to make informed decisions for recommending the use of bottom ash as a fill or landfill liner material, depending on the project requirements.

Conclusions

In order to use PCC bottom ash amended with bentonite for fill or landfill liner purposes, estimation of its swelling potential is necessary. In addition, due to chemical composition of PCC bottom ash, it is important to understand the effect of curing on the swelling properties of bottom ash-bentonite mixtures. In this investigation, effect of curing and initial moisture content of bottom ash-bentonite mixtures on their free swell potential was studied by conducting a series of free swell tests. Specimens containing 15 and 20 percent bentonite by dry weight of the mixture and prepared at initial moisture contents of 14, 16 and 18 percent were tested at curing ages of 0, 7, 28 and 60 days. Results presented show a rapid increase in free swell until approximately 16 hours after inundating them with water. Beyond this point, the free swell was observed to be minimal. The free swell also decreased as the curing period at a constant moisture content increased. For all specimens made with 15 percent bentonite and specimens made with 20 percent bentonite at initial moisture content of 18 percent, decrease in the free swell is likely to be marginal after 60 days of curing. However, for specimens with 20 percent bentonite and initial moisture contents less than 18 percent, further decrease in the swell potential is likely. The free swell potential also decreased significantly as the initial moisture content increased. After 60 days of curing, bentonite content was observed to have insignificant effect on the free swell potential of the mixtures. The results and trends presented would be helpful to design engineers in making informed decisions for recommending the use of appropriate bottom ash-bentonite mixtures on construction projects.

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