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LOAD-DEFORMATION BEHAVIOR OF BENTONITE AMENDED BOTTOM ASH IN BENDING

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ABSTRACT

Modulus of rupture of concrete is frequently used for design of concrete structures whereas flexural strength of soils is generally ignored during analysis and design of earth structures. However, geotechnical engineers still study the bending load-deformation behavior of soils because it is useful in understanding of cracking of earth embankments and compacted clay liners, particularly when they are subjected to bending stresses caused by uneven settlements. A laboratory study was conducted to measure load-deformation behavior of Illinois PCC bottom ash amended with bentonite in bending using the conventional flexural strength test. This paper presents the bending load-deformation results obtained from this study.

INTRODUCTION

Although it is usually reasonable to neglect the tensile and flexural strength of soil in the analysis and design of earth structures, knowledge of the behavior of soils in tension and flexure is still useful for understanding of cracking in earth embankments (Krishnayya, et al. 1974). This quest has encouraged a number of investigators to study the flexural strength behavior of soils.

Over 50 percent of the total electricity produced in the United States is generated from coal burning (Kalyoncu, 2001). Burning of coal, combined with pollution control technology generates large quantities of by-products (Illinois Coal Fact Sheet, 2003) commonly referred to as coal combustion by-products (CCBs). Fly ash, which consists of about 60% of the CCBs (ACAA 2002), has consistent grain size and properties. This has resulted in its increasing use and there have been some intensive studies particularly focused on the usability of fly ash as an engineering material (e.g. Twardowska, 1990; White and Case, 1990). Bottom ash, on the other hand has relatively inconsistent grain sizes and properties and has not gained much ground in construction market. Although there have been several studies to investigate geotechnical characteristics of bottom ash with or without admixtures (e.g. Seals et al., 1972; Leonards and Bailey, 1982; Huang and Lovell, 1990; Kumar and Stewart, 2003; Kumar and Vaddu, 2004a,b), use of bottom ash in geotechnical applications is still limited to structural fills/embankments and road base/sub-base constructions.

Bottom ash obtained from pulverized coal combustion (PCC) power generating plants has physical characteristics which are similar to those of natural sand. Therefore, many studies have progressed over the past decade to utilize bottom ash from PCC instead of natural sand in construction applications. Recently, Kumar and his team have studied its properties modified with various admixtures for use in geotechnical engineering applications. The studies have shown that the compressive strength of bottom ash-bentonite mixtures increases with time due to reactions between bottom ash and bentonite in the presence of water. Mellor and Hawkes (1971) and Narain and Rawat (1970) have presented results on tensile strength tests on soils. However, literature showing the flexural strength of bottom ash modified with any admixture is still not available. Therefore, the present study was initiated to evaluate bending stress-strain characteristics of bottom ash amended with bentonite.

Bottom ash and bentonite are physically and chemically two different types of materials with contrasting properties. While bottom ash acts like an aggregate giving strength to the matrix, bentonite works as a binding and filling material, in effect making it similar to clayey sand type of geomaterial. A research done by Kumar and Vaddu (2004b) showed that the bottom ash undergoes a chemical reaction with bentonite in the presence of water to form bondage structures at micro level; thus, impacting increased strength with curing age (Figure 1). However, the amount of bentonite that can be used in modifying the strength characteristics of bottom ash is limited by its tendency to swell. Kumar and Vaddu (2004a) studied the swelling pattern of the bottom ash-bentonite mixture compacted at 15.7 kN/m^3 dry unit weight. They observed that the amount of free swell at moisture content of 18 to 20 percent for mixtures with 15% bentonite was less than 4 percent and that for mixtures with 20% bentonite was between 6 to 9 percent. Based on their experiences, they concluded that these values fall within the range for use in construction (Kumar and Vaddu, 2004a). This knowledge has been used in this investigation to establish the proportion of the mixture ingredients.

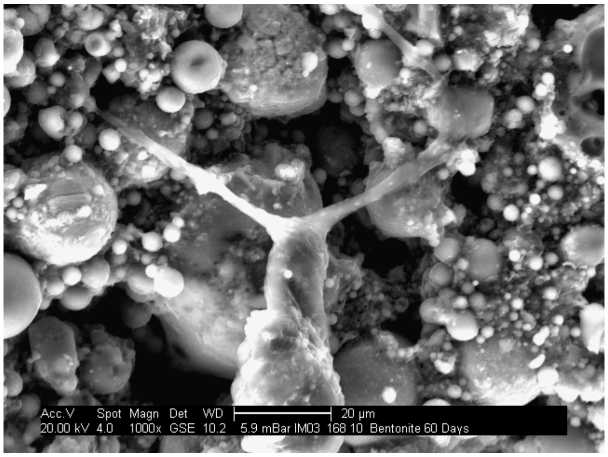

Fig. 1. ESEM image of bottom ash amended with bentonite after 60 days of curing (Kumar and Vaddu, 2004b)

SPECIMEN PREPARATION

Bottom ash-bentonite mixture was prepared by thoroughly mixing the calculated amount of bentonite and bottom ash so that the amount of bentonite in the mixture was 15% of the total dry weight of the mixture. The samples were compacted at 18% moisture content and a dry unit weight of 15.7 kN/m^3. These values were selected based on the results obtained from previous standard Proctor tests conducted by Kumar and Stewart (2002). A dismantlable double compartment rectangular steel mold (Figure 2) with each compartment of size 50.8 mm X 50.8 mm X 220 mm (2 in X 2 in X 8 ¾ in) was used to mold the specimens for flexure test. The moist bottom ash-bentonite mixture was compacted in each compartment in 3 equal layers. The amount of mixture was weight controlled so that the specimen had a uniform dry unit weight of 15.7 kN/m^3. The top of each layer was scarified before placing the next layer to ensure proper bondage between the layers. The specimens were extracted by dismantling the mold.

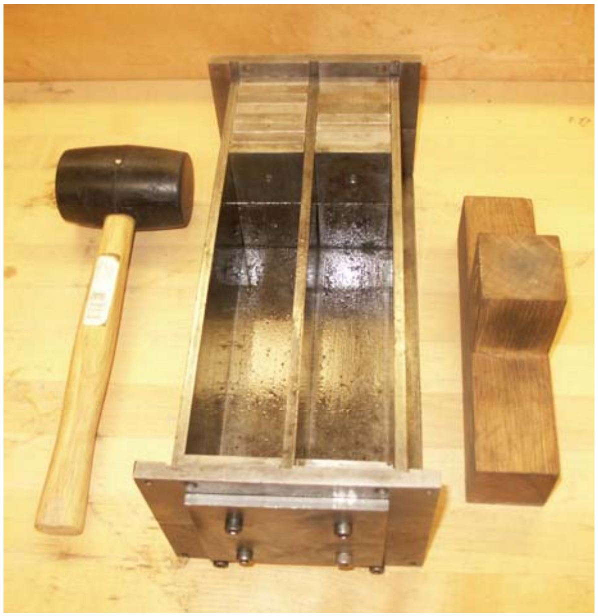

Fig. 2. Picture of the mold used to prepare test specimens

LOAD-DEFORMATION BEHAVIOR

The most common parameter to estimate the flexural strength of a material is Modulus of Rupture (MoR). The samples were tested using the third-point loading method. At least two specimens were tested. Figure 3 shows load deformation responses from both the samples. The samples were tested immediately after compaction. The MoR value was calculated based on the peak vertical load. Additional test results are presented elsewhere (Adhikari, 2004).

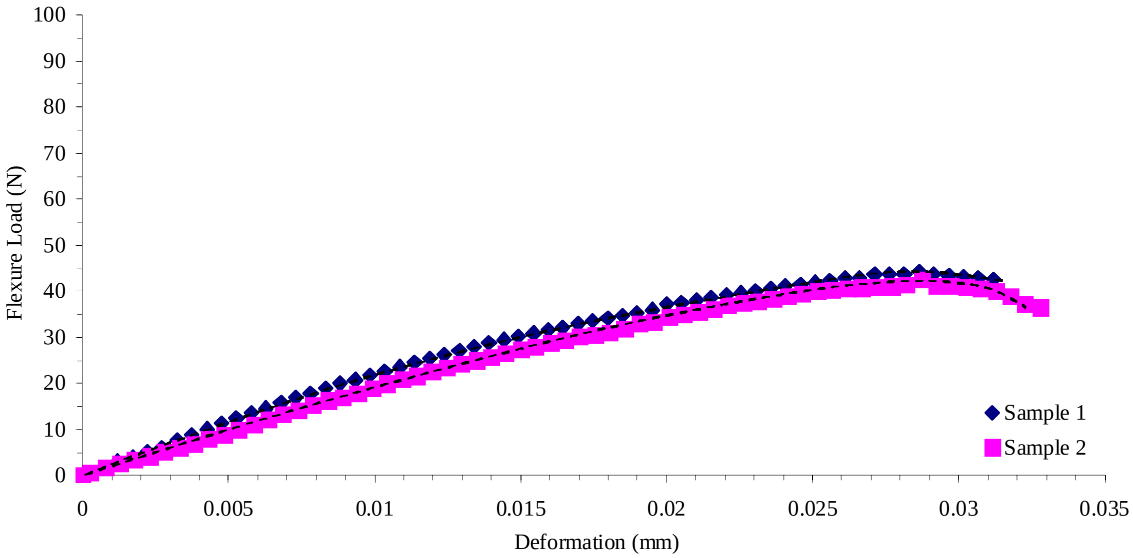

Fig. 3. Load-deformation curves from flexure test from samples tested immediately after compaction

Results presented in Fig. 3 show that the load-deformation relationship is linear in the first loading phase and gradually become non-linear close to the failure point. After reaching a peak load, the specimens did not take any more load, showing a sudden decrease in load value within a small increment of strain. Consequently, a peak was observed in almost every load-deformation curve. The highest value of load at the peak was considered as the failure load and was usually accompanied by a transverse crack formation at the center of the specimen. This peak value was then used to calculate MoR. Deformation at the failure load was taken as the failure deformation.

As discussed earlier, compressive strength results obtained by Kumar and Vaddu (2004b) showed that the bottom ash undergoes a chemical reaction with bentonite in the presence of water to form bondage structures at micro level; thus, impacting increased strength with curing age. In order to measure the change in bending load-deformation behavior of bottom ash-bentonite mixture with curing age, tests were also conducted after curing the samples for various periods. Figure 4 shows the load-deformation responses of samples tested after 28 days of curing. Results presented in Fig. 4 show trends very similar to those observed from samples tested immediately after compaction. However, the peak load taken up by the samples is approximately 43 percent greater then that resisted by samples tested immediately after compaction.

Figure 5 shows the effect of curing on the modulus of rupture response. The results presented in Fig. 5 show that the flexural strength of the bottom ash-bentonite mixture increased with the increase in the curing period up to 60 days of curing but reduced when cured for 94 days. This could have been the result of formation of brittle skeletal matrices formed within the specimen over the curing period.

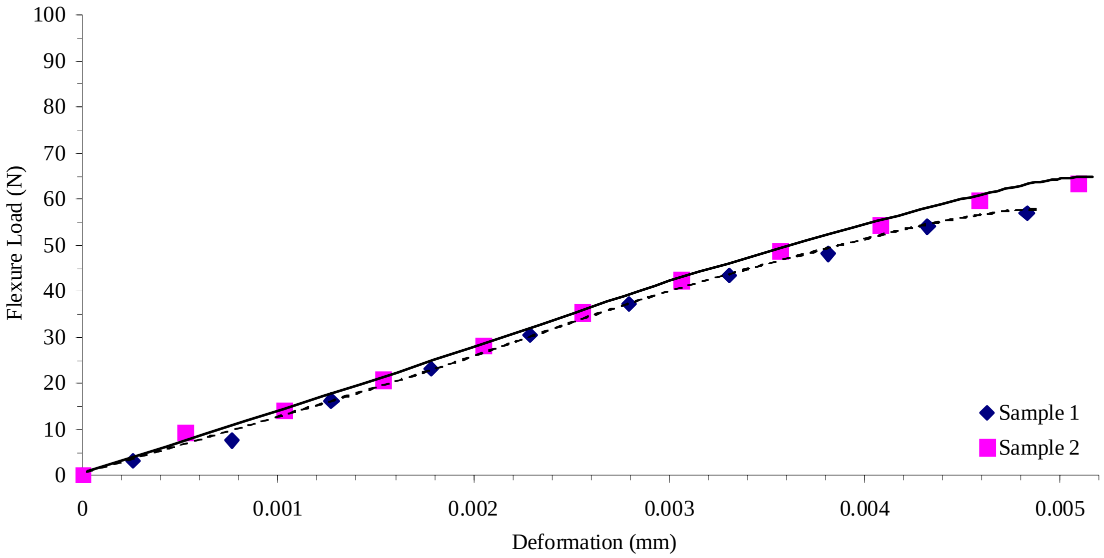

Fig. 4. Load-deformation curves from flexure test on samples cured for 28 days

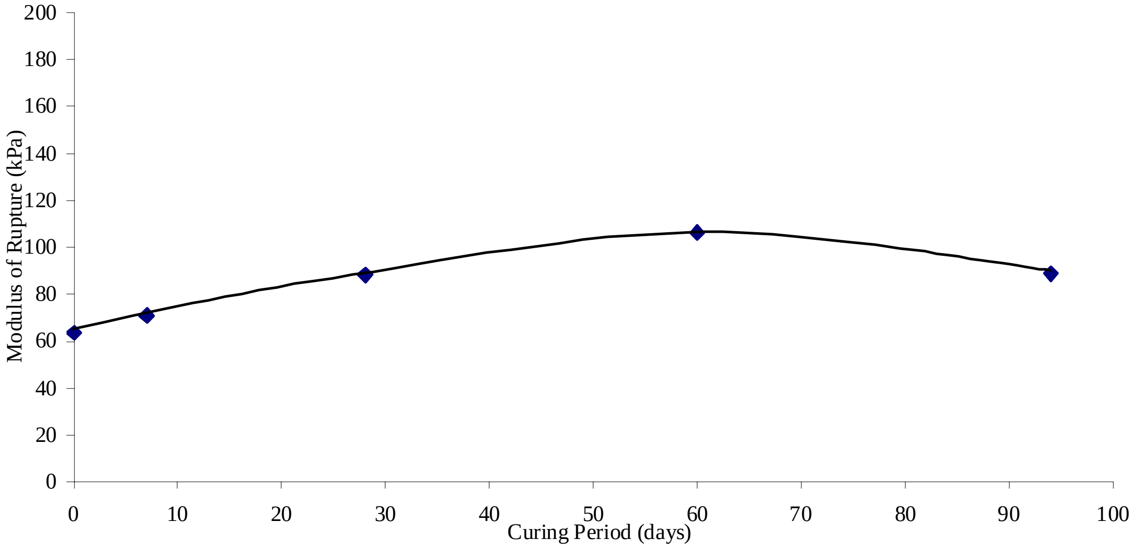

Fig.5. Variation of modulus of rupture of specimens with curing period

CONCLUSIONS

A series of laboratory tests were performed on bottom ash-bentonite mixtures to understand their bending load-deformation behavior. The results presented showed that the bending load-deformation response of compacted bottom ash-bentonite specimens was linear for the most part of stress condition before failure. However, the response became non-linear as it approached the critical failure stress condition. The failure generally occurred beyond the linear elastic range shortly after the response became nonlinear. Results also show that the modulus of rupture of the compacted bottom ash-bentonite mixtures increased with the increase in the curing period up to about 60 days of curing. After that the flexural strength decreased with the increase in the curing period. This could have been the result of formation of brittle skeletal matrices formed within the specimen over the curing period.

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