Assessing the Suitability of Compacted Bentonite-Pond Ash Mixes as Landfill Liner

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ABSTRACT: The use of compacted bentonite-sand mixes as landfill liner has been accepted worldwide. However, the non-availability of sand at all landfill sites triggers a search for an alternate material. Pond ash is an industrial waste and has the distinct advantage of a geotechnical material as it resembles the natural earth material. Moreover, it has the similar mineralogical composition to conventional earth materials and needs special attention for its effective utilization rather than disposing of it by consuming large land area leading to the loss of agricultural production. With the addition of bentonite to the pond ash, the plasticity, and strength is expected to increase whereas the permeability is expected to decrease. Further, as pond ash is non-plastic and possesses very low shrinkage, it is expected to reduce the swelling and shrinkage, preventing the formation of any cracks in the compacted liner material. The present study examines the suitability of compacted bentonite-pond ash mixes as landfill liner material. The proportion of bentonite in the pond ash-bentonite mix is varied from 5 to 30% by weight at 5% intervals. The plasticity characteristics, compaction properties, strength and permeability properties of pond ash-bentonite mixes are evaluated. It is observed that with the addition of bentonite the plasticity index, maximum dry density, differential free swell index, cohesion, and compressive strength increases gradual and on the other hand the optimum moisture content, hydraulic conductivity, and frictional angle decreases. It is also found that an addition of 5% bentonite has no effect on the geotechnical properties of pond ash. The designed mixture with 20% bentonite attained its plasticity index, strength and permeability values as per the requirements of a suitable landfill liner material as per the EPA regulatory act.

***Key words*:** pond ash, bentonite, landfill liner, geoengineering properties.

INTRODUCTION

With the growing industrialization and population, wastes are generated more and more. Based on the safety level, these wastes can be hazardous or non-hazardous. These wastes can be controlled by recycling, incineration, transformation and environmentally sustainable disposal on land. Despite all effort, the most frequently used option is disposing of waste in the landfill due to its efficiency and low cost. The liner is the essential component of a landfill. According to EPA regulatory, liner must have adequate strength with minimum hydraulic conductivity and plasticity index should vary between 10 to 30%. Previously, clay has been used as a liner material due to its low cost, large leachate attenuation capacity and resistance to damage and puncture. Nowadays many more researchers have found out that compacted clay can be effectively replaced by wastes and any other material. Kayabali (1997) conducted tests on seven different ratios of bentonite to zeolite to obtain a mix ideal as landfill liner material. Owing to its swelling ability, bentonite content serves as pore-sealant at the saturated condition. The optimum water content and the corresponding dry density ranged from 33 to 42% and 1.16 to 1.26 g/cc, respectively. At the smallest ratio of bentonite to zeolite (i.e., 0.05), the water content of the bentonite component was as high as 850%, and full saturation was reached. The average range of hydraulic conductivity obtained was 2×10^{-8} to 4×10^{-8} cm/s. Mohamedzein et al. (2005) investigated the use of two types of crushed shales as a liner material by conducting different laboratory tests. It was concluded that both the shales satisfied the basic properties of the liner having low compressibility and hydraulic conductivity for all level of compaction and the shear strengths were with the acceptable range of earthen material. Tanit and Surapon (2005) conducted direct shear and hydraulic conductivity tests to assess the shear strength parameters and hydraulic conductivity of compacted sand-bentonite mixtures. Test results indicated that the hydraulic conductivity of mixtures decreased about four orders of magnitude when mixed with 5% bentonite or more. Based on test results, a suitable sand-bentonite mixture that yields low hydraulic conductivity, while maintaining relatively high shear strength, was recommended for use as a liner in hydraulic containment applications. Shankar and Phanikumar (2011) studied the variation of index properties with the concentration of permeating fluids. This paper proposed an innovative clay liner material in the form of fly ash-stabilised expansive clay and presented the experimental findings on the variation of index properties and free swell index (FSI) values of the blend with varying fly ash content in the blend and concentration of salt solutions. The various permeating liquids used were deionized water and salt solutions such as $CaCl_2$, NaCl, and KCl. It was observed that with an increase in the fly ash content for all concentrations of salt solution, the liquid limit (LL), FSI and hydraulic conductivity decreased. A correlation between LL and FSI has been established for the liner material. Akcanca and Aytekin (2012) studied the influence of wetting–drying cycles on swelling pressures of sand–bentonite mixtures used in the construction of sanitary landfills before and after lime treatment of the mixtures. The specimens were prepared by mixing bentonite in various proportions with their OMC and also lime was added to the sand bentonite mixture. Both the specimens were compacted with standard Proctor energy. The test results indicated that the swelling pressures of the specimens made of sand–bentonite mixtures stabilized by lime were lower than the swelling pressures of the specimens made of only sand–bentonite mixtures. Also, the swelling pressure is found to reduce by wetting–drying cycles. The present study examines the suitability of compacted bentonite-pond ash mixes as landfill liner material. The proportion of bentonite in the pond ash-bentonite mix is varied from 5 to 30% by weight at 5% intervals. The plasticity characteristics, compaction properties, strength and permeability properties of pond ash-bentonite mixes are evaluated.

MATERIALS AND METHODOLOGY

Materials

The basic raw materials used in this experimental program are pond ash and commercial bentonite. Pond ash (PA) used in this study was collected from the ash pond of the national thermal power plant (NTPC), Angul (Odisha). These samples were collected from the outlet points of slurry pipes. The samples were mixed thoroughly to bring homogeneity and dried at an oven temperature of 105-1100C. The geotechnical properties of the pond ash (PA) and bentonite (B) are given in Table 1. Commercially available sodium bentonite of Neelkanth Minechem, Jodhpur, (India) is used in this experimental program. According to the IS soil classification system, it is classified as high plasticity clay (CH) as plasticity index of bentonite is more than 50%. The grain size distribution curves for both the materials are shown in Fig.1. Synthetic mixes are prepared by mixing bentonite with pond ash in different proportions. The percentage of bentonite in the mix is varied from 5 to 30% by weight at 5% intervals, and these mixes are designated as B5, B10, B15, B20, B25, and B30 respectively.

Methodology

In this present study, synthetic mixes are prepared by adding bentonite of 5 to 30% by weight at 5% intervals with the pond ash. In this manner, six different mixes were synthesized. The basic properties like plasticity characteristics, specific gravity, and differential free swell index values are evaluated to check whether it meet the liner requirement. The OMC and MDD of these mixes corresponding to compactive efforts of 595 kJ/m^3 and 2674 kJ/m^3 are determined as per IS: 2720 (Part 7) 1980 and IS: 2720 (Part 8) 1983 respectively. Before the compaction tests, these synthetic materials were mixed with initial water and were kept in an airtight container for 48 hours for proper distribution of water in the mix. To find out the shear strength parameters synthetic mixes were compacted in standard Proctor mould to their respective MDD at OMC using compactive efforts of 595kJ/m^3, and 2674 kJ/m^3. Undisturbed specimens of size 60mm×60mm×25mm were recovered from the mould and were sheared at a rate of 0.2 mm/min. The shear parameters (i.e. c and Φ values) were found out from the plots between normal stress and shear stress. These tests were performed as per IS: 2720 (Part 13) 1986. Unconfined compressive strength tests on specimens compacted to their corresponding MDD at OMC was performed according to IS: 2720 (Part 10) 1991. The cylindrical test specimens were of size 50mm in diameter and 100mm in height, and these were sheared at an axial strain rate of 1.25 mm/min. Hydraulic conductivity of different pond ash-bentonite mixes, compacted to their respective MDD at OMC are evaluated as per IS: 2720(Part 17) 1987.

RESULT AND DISCUSSION

A well designed compacted clay liner must have required plasticity, minimum fines content and a low permeability to prevent or minimize leachate leakage, adequate shear strength for stability and minimal shrinkage potential to prevent desiccation cracking. The design objective for a compacted clay liner is to determine the range of water content and dry unit weight within which compacted test specimens will have low hydraulic conductivity, adequate shear strength and minimal shrinkage upon drying. Some index and engineering properties are scrutinized based on the addition of the bentonite to pond ash.

Index Property

The index properties of the pond ash, bentonite, and the mixes i.e. specific gravity, grain size distribution and plasticity characteristics are evaluated and presented. The specific gravity of pond ash and bentonite was found to be 2.23 and 2.70 respectively. The specific gravity of pond ash is comparatively lower than the similar graded conventional earth material. The specific gravity of resulting flyash is affected by the presence of foreign materials in the coal fissures, and it also depends on the source of coal, degree of pulverization and firing temperature. Moreover the pond ash is subjected to mixing with other earth materials during its transportation and depositions, which influences its specific gravity (Singh et al., 2014 and Asrith et al., 2015). Though the chemical composition of pond ash is very much similar to earth material but as the particles are cenospheres, it results in a lower specific gravity. The pond ash consists of grains mostly of medium to fine sand size with fines content (< 75μm) of 1.99% only. The coefficient of uniformity and coefficient of curvature are 1.15 & 2.91 respectively, indicating uniform gradation of samples. The sample is classified as 'SP' as for unified soil classification system. The fines content of the commercial bentonite is 96.93%, and as per unified soil classification system it is classified as 'CH'. The grain size distribution curves of pond ash and bentonite is presented in Fig.1. The test results show that the pond ash is a non-plastic material whereas bentonite is highly plastic in nature. Both the liquid limit (LL) and plastic limit (PL) of the pond ash-bentonite mixture could not be determined up to bentonite content of 10% in the mix and these mixes are reported as to be non-plastic. However, with further increase of bentonite content of the mix, it behaved as plastic material and both the LL and PL is found to increase significantly with increase in bentonite content of the mixture. When small amount of bentonite is added to the pond ash sample, these finer particles of bentonite get entrapped in the intra-particle and inter-particle void space of pond ash. As the percentage of fines in the mixture is increased these particles tries to coat the surface of the ash particles thus imparting plasticity to the mixture. As the amount of water needed to satisfy the double layer of bentonite is very high an addition of bentonite above threshold amount to pond ash significantly increases both the liquid limit and plastic limit of the mix (Fig. 2). An increase in the bentonite content in the mix, results a marginal decrease of shrinkage limit (SL) value. This is due to the development of high suction force in the capillary pores of the desiccating pond ash–bentonite specimens with higher bentonite content. On the other hand, the differential swelling index value increases with the increase in bentonite content due to the presence of montmorillonite mineral in bentonite, which even allowed more water to enter into unit layers. The variation of the DFS value of the mix with bentonite content is shown in Fig. 3.

Compaction Characteristics

Figs. 4(a) and 4(b) show the compaction curves of pond ash bentonite mixes compacted with standard and modified Proctor energies respectively. It is observed that as the bentonite content increases the compaction curves shifts towards the left that is an addition of bentonite to the pond ash results in a decrease of the OMC value up to an optimum bentonite content after that, it remains almost unchanged. This behaviour is observed for samples compacted with either standard or modified Proctor compaction energies. As seen from the gradation curves of pond ash and bentonite both the materials are uniformly graded, and the particle of pond ash ranges from fine to medium sand size while for the bentonite it is mostly clay size particles. An addition of bentonite to pond ash changes the gradation making the mixture better graded from uniformly graded material. The change in gradation results in a well packing of particles during compaction thus increases the MDD value (Fig. 5) and reducing the OMC value of the mix. Fig. 6 shows the variation of MDD with bentonite content. It is found that with the addition of bentonite to pond ash, MDD value increases up to an optimum bentonite content after that it remains almost constant. This trend is observed for samples compacted either with 595kJ/m3 or 2674 kJ/m3 energy. The optimum content of bentonite for both the cases is found to be 20%. This may be due to the fact that when bentonite percentage is small, the finer particles of bentonite mostly try to enter into the intra-void spaces present in the conglomerated ash particles. As the percentage of bentonite is further increased, these particles filled-up the inter-particular void spaces available in the pond ash sample. This increases the MDD value. Further increase of bentonite creates a space for itself forcing the ash particles to move apart, thus stabilizing the MDD value.

Hydraulic Conductivity

Hydraulic conductivity values of bentonite-pond ash mixes compacted with 595 kJ/m^3 and 2674 kJ/m^3 energy are found to be in the range of 8.83×10^{-4} to 9.23×10^{-9} cm/s and 3.42×10^{-4} to 5.15×10^{-9} cm/sec respectively. The variation of hydraulic conductivity with bentonite content is shown in Fig. 7. It is obvious that an increase of bentonite content in the compacted mixtures lowers the hydraulic conductivity values. This is verified by many studies. Since bentonite alone has characteristics of the impervious material and has extremely low hydraulic conductivity values in the order of 10^{-10} to10^{-12} cm/s, it is expected to have lower hydraulic conductivities as its percentage in the mixture increases. The experimental data shows that the reduction in hydraulic conductivity with bentonite content is not linear. Initially, the rate of reduction is mild followed by a sharp decrease in the hydraulic conductivity value. At low bentonite content, the finer bentonite particles get adjusted in the intra-particle void space of pond ash thus there is an appreciable reduction in capillary void space. However, as its content increases it reduces the capillary void thus a sharp reduction in the hydraulic conductivity value.

Unconfined Compressive Strength

Unconfined compressive strength test is performed for sample compacted with both 595 kJ/m^3 and 2674 kJ/m^3 energy. Compressive strength of pond ash-bentonite mixture compacted for both the energy are found be in the range of 52 to 197 kPa and 99 to 691 kPa respectively as shown in Fig. 8. As per the general requirement of isolation material such as liner, the compressive strength should have a value more than 200 kPa. The above strength is accomplished for the samples containing 15% or more bentonite and compacted with 2674 kJ/m^3 energy.

Shear Strength Parameter

Shear strength parameters such as unit cohesion (c) and internal friction angle (ϕ) are found to be in the range of 16.27 to 63.81 kPa and 42.5° to 28.4° for mixtures compacted with 595 kJ/m^3 energy, 12.67 to 89.59 kPa and 44.6° to 30.9° for the mixtures compacted with 2674kJ/m^{3}energy when the bentonite content of the mixture is changed from 5 to 30%. Figs. 9 and 10 present the variation of unit cohesion and angle of internal friction with bentonite content. It is seen that as the bentonite content increases, the cohesion increases and internal friction angle decreases. This may be due to the fact that as pond ash particles are irregular in shape, there exist a good interlocking between the particles hence the angle of internal friction is high. When a smaller amount of bentonite is added to the mixture, the finer particle of bentonite tries to fill the intra-void spaces present in the conglomerated ash particles. But as the bentonite content increases, the excess bentonite coats the surfaces of the ash particle. As bentonite particles are lubricative in nature, the bentonite coated pond ash particles losses their contact and slips over each other and hence frictional angle decreases. However, due to the presence of strong inter-particular attractive forces between the bentonite particles the mixture gradually develops cohesion with an increase in bentonite content.

CONCLUSION

The suitability of pond ash-bentonite mixes as landfill liner material was investigated in this work. The compaction, strength, and hydraulic conductivity characteristics are evaluated. Based on the experimental investigation, the following conclusions are drawn:

- From the grain size distribution curve, it was inferred that the pond ash is a non-plastic material whereas bentonite is highly plastic in nature. It was also inferred that the percentages of fines content (< 75μm) present in pond ash and bentonite are 1.99 and 96.93 respectively. Both the LL and PL was found to increase significantly and on the other hand; differential swelling index value was increased from 34 to 87% with the increase in bentonite content.
- When the samples were compacted with compactive effort of 595 kJ/m^3 the maximum dry unit weight increases from 11.13 to13.14 kN/m^3 and the corresponding optimum water content of the compacted mixtures decreases from 32 to 22.5% as the bentonite content varies from 5 to 30%. However with the compactive effort of 2674 kJ/m^3, the maximum dry unit weight increases from 13.54 to 15.6 kN/m^3 and the corresponding optimum water content decreases from 23.75 to 16.5%
- The compressive strength of pond ash-bentonite mixture compacted for both the energy were found vary from 52 to 197 kPa and 99 to 691 kPa respectively.
- Shear strength parameters such as cohesion (c) and internal friction angle (ϕ) was found to be in the range of 16.27 to 63.81 kPa and 42.54° to 28.4° for mixtures compacted with compactive effort of 595 kJ/m^3. These values are 12.672 to 89.59 kPa and 44.55° to 30.90° for the mixtures compacted with compactive effort of 2674 kJ/m^3.

From this study, it can be concluded that sand bentonite mixture can effectively be replaced by pond ash bentonite mixture when sand is not easily available and wastes are to be utilized.

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Table 1 Geo-engineering property of pond ash and bentonite

Parameters	Bentonite	Pond ash
Colour	Cream	Light grey
Particle shape	Flaky type	Sub-rounded to irregular
Fines content, <75µm (%)	96.93	1.99
Fine sand (%)	3.07	64.28
Medium sand (%)	0	33.73
Median diameter, D_{50} (mm)	0.04	0.28
Uniformity coefficient, C_u	-	2.91
Coefficient of curvature, C_c	-	1.15
Specific Gravity, G	2.7	2.23
Liquid limit (%)	301	Non-plastic
Plastic Limit (%)	65	
Shrinkage Limit (%)	9.42	
Plasticity index (%)	236	
OMC (%)	32	27
MDD (kN/m^3)	13.53	11.63

FIGURES

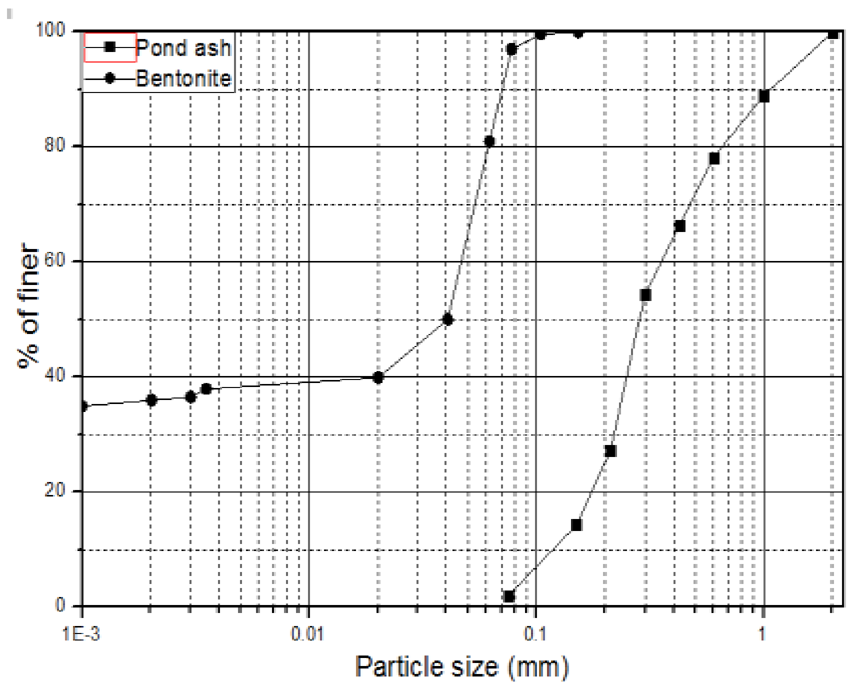

FIG. 1. Grain size distribution curve of pond ash and bentonite

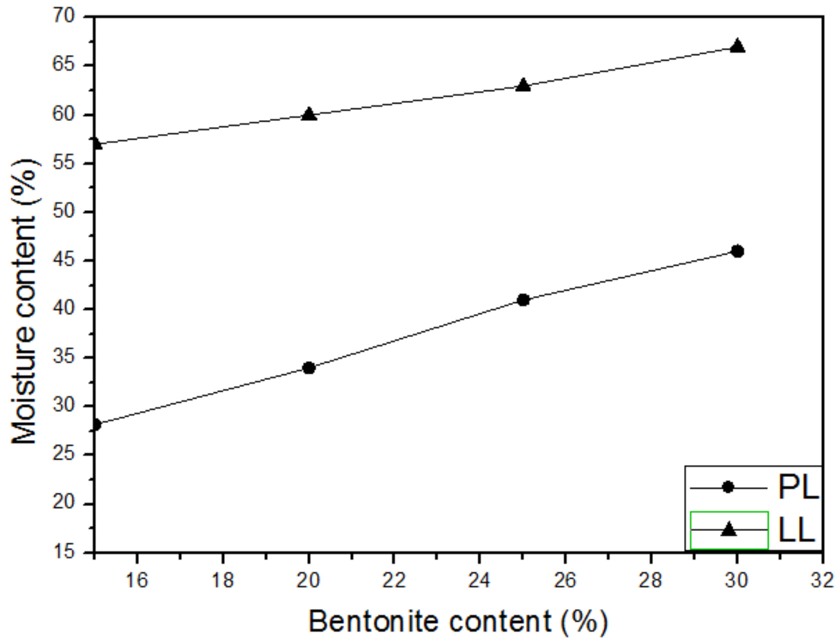

FIG. 2. Variation of liquid limit (LL) and plastic limit (PL) with bentonite content

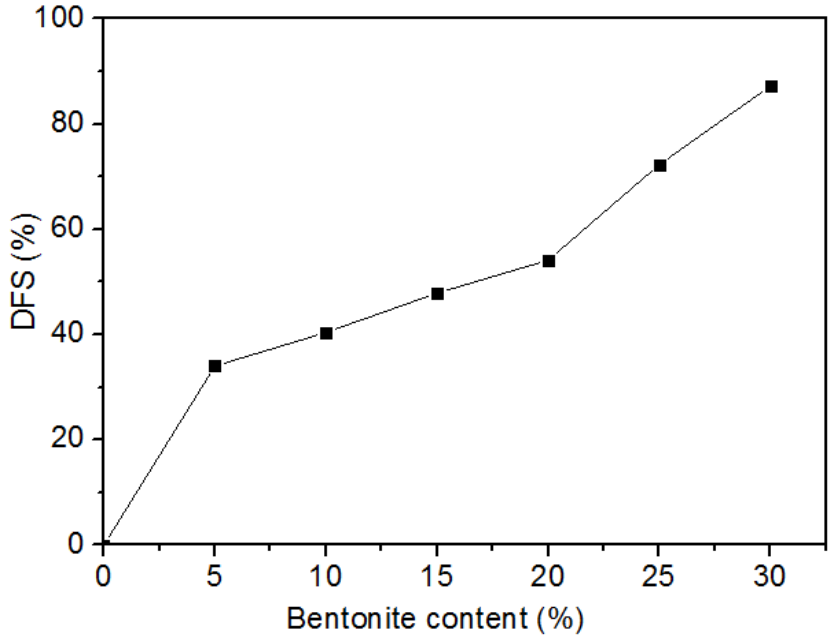

FIG. 3. Variation of DFS value with bentonite content

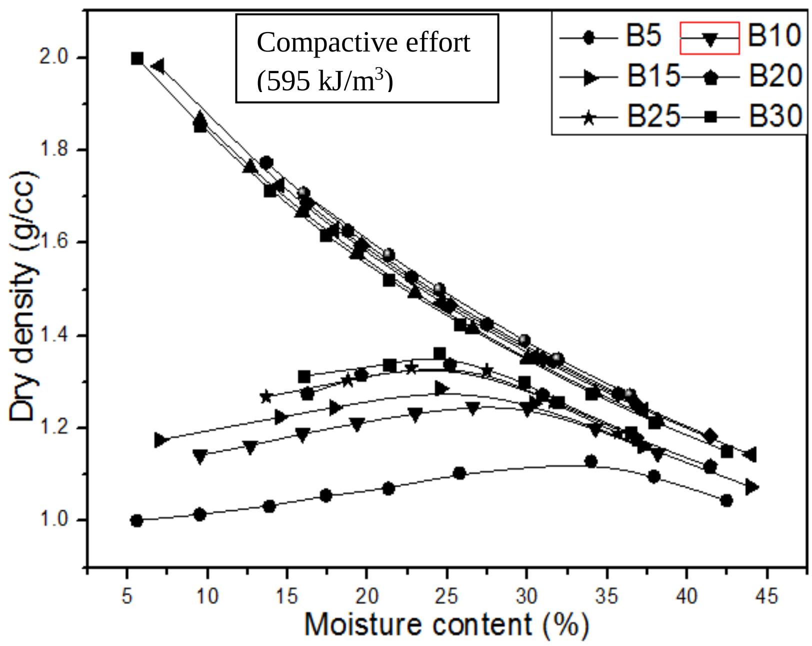

FIG. 4(a). Compaction curves of pond ash-bentonite mixes at standard Proctor energy

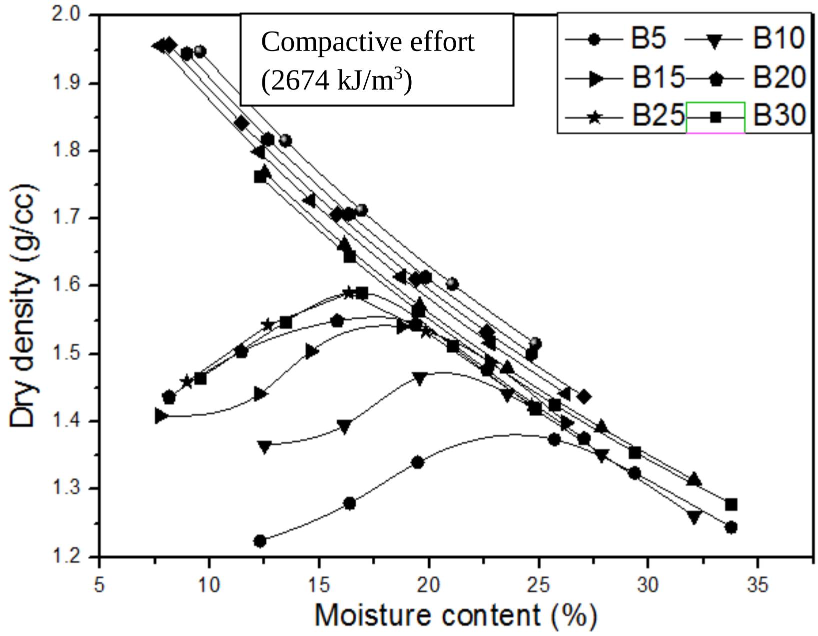

FIG. 4(b). Compaction curves of pond ash-bentonite mixes at modified Proctor energy

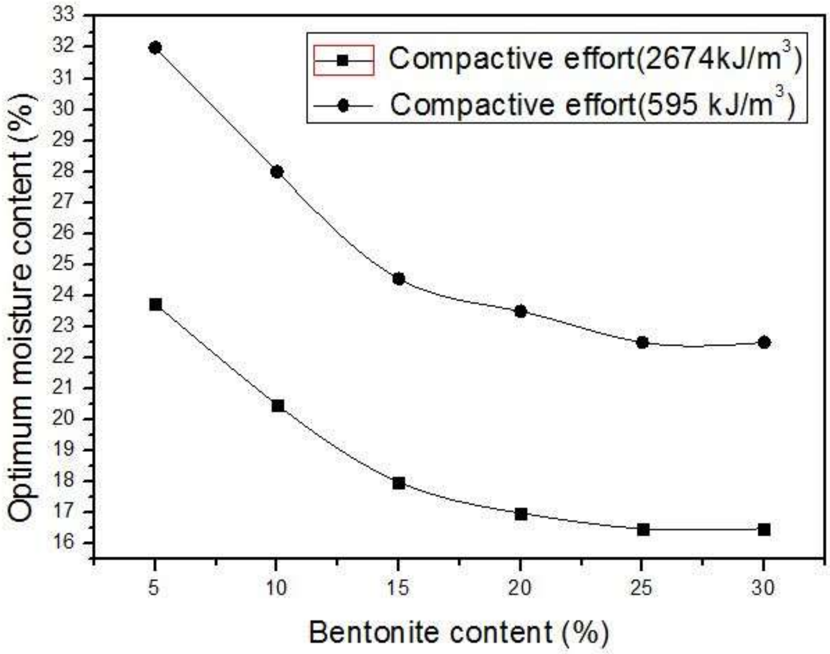

FIG. 5. Variation of OMC with bentonite content

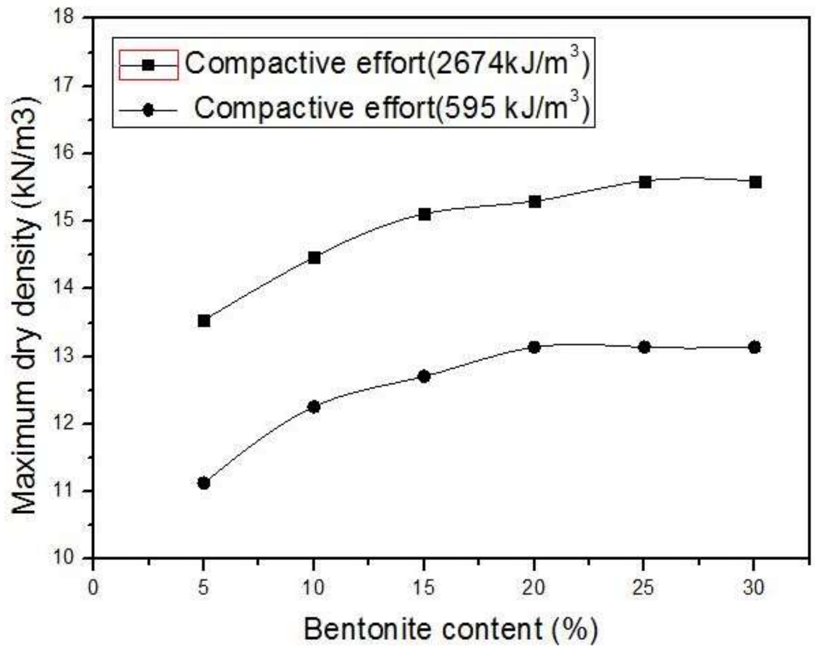

FIG. 6. Variation of MDD with bentonite content

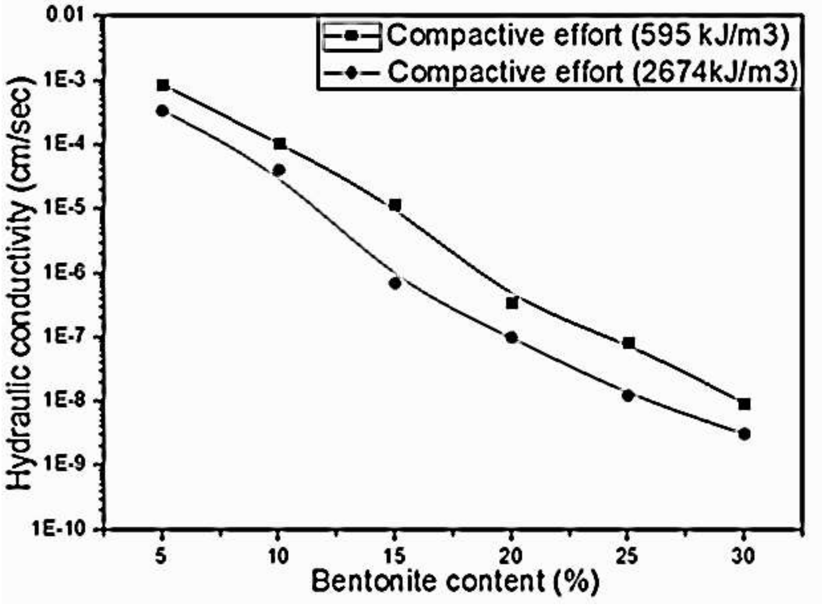

FIG. 7. Variation of hydraulic conductivity with bentonite content

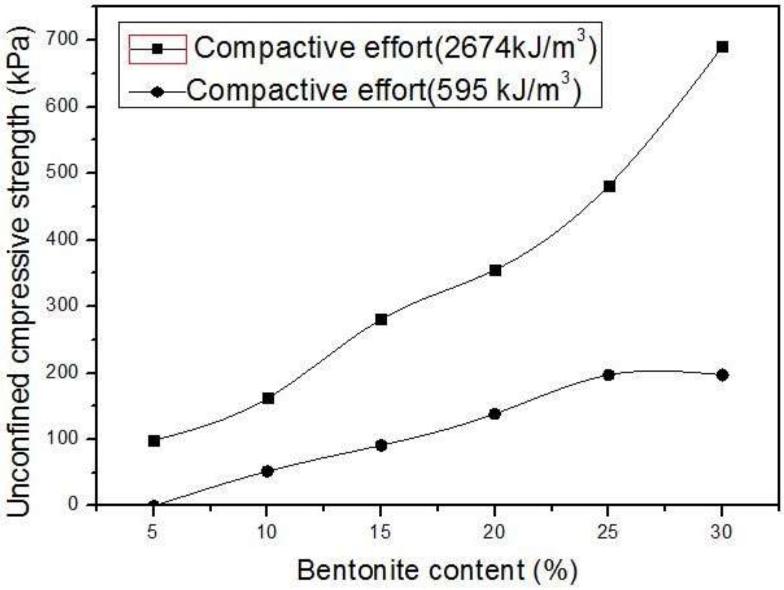

FIG.8. Variations of unconfined compressive strength with bentonite content

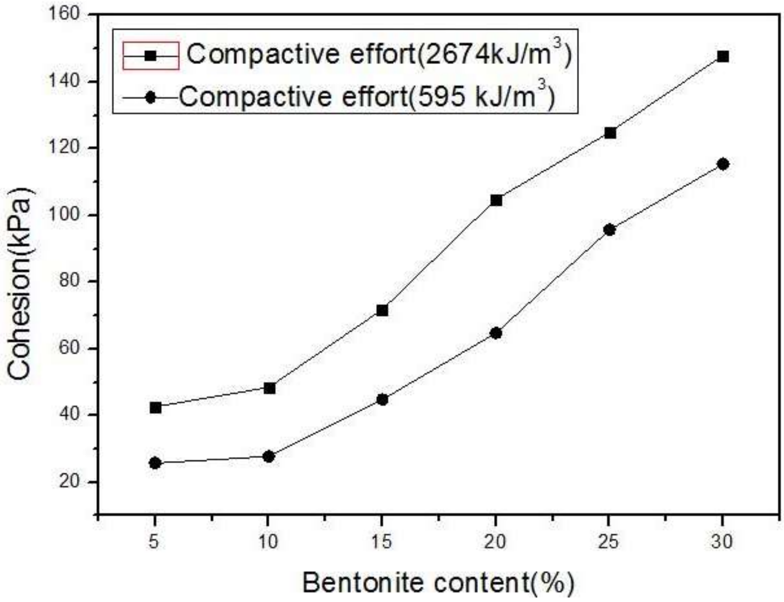

Fig. 9. Variations of cohesion with bentonite

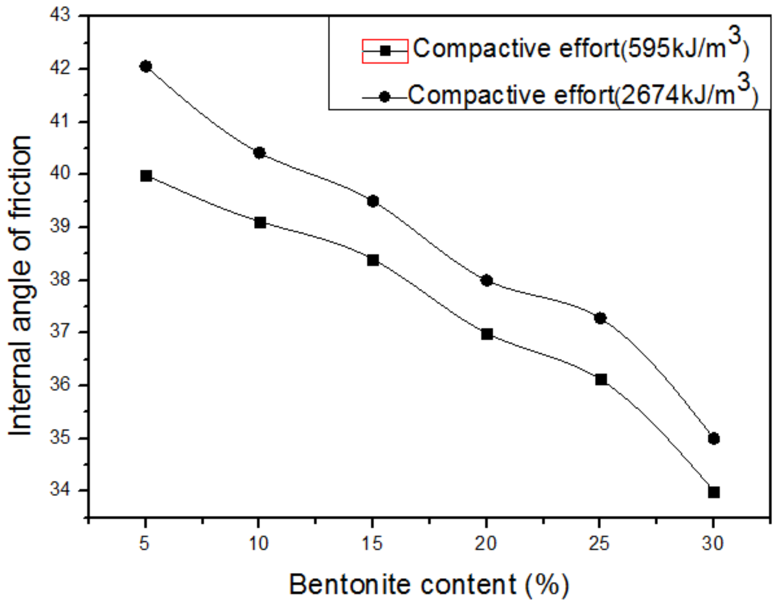

Fig. 10. Variations of internal angle of friction with bentonite content