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Research paper

Polypropylene fiber reinforced bentonite for waste containment barriers

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ABSTRACT

The present study examines the relevance of placement conditions on the behaviour of polypropylene fiber reinforced bentonite. The laboratory testing program includes conducting standard and modified Proctor compaction tests, tracing shrinkage behaviour, performing hydraulic conductivity and unconfined compression strength tests on both unreinforced and fiber reinforced bentonite. An overall acceptable zone in terms of water content and dry unit weight is established by considering the hydraulic conductivity, strength and volumetric shrinkage criteria. The experimental results showed that the volumetric shrinkage criterion controlled the overall acceptable zone for unreinforced and fiber reinforced bentonite specimens in compacted state. However, the hydraulic conductivity values of fiber reinforced bentonite specimens subjected to wet-dry cycles show that the shrinkage criteria may not be appropriate for materials such as bentonite and bentonite-enhanced clays which possess good self sealing properties; and for such materials the hydraulic conductivity needs to be evaluated after wet-dry cycles. As the basic ingredient of geosynthetic clay liners (GCLs) is bentonite clay, the relevance of the placement conditions is discussed for the GCLs.

1. Introduction

Geosynthetic clay liners (GCLs) are being extensively used as a part of composite liners in waste containment applications to restrict the flow of water and leachates due to their low hydraulic conductivity, good self-healing characteristics, low cost, occupies less space in comparison with the conventional compacted clay liners and the scarcity of suitable clayey soils for the construction of conventional compacted liners at the landfill sites (Kolstad et al., 2004; Southen and Rowe, 2004; Shackelford et al., 2010; Sivapullaiah and Baig, 2011; Sari and Chai, 2013; Bouazza and Gates, 2014; Li et al., 2014). The bentonite is the basic constituent of GCLs which imparts the aforesaid characteristics to GCLs for barrier applications. The bentonite is encased between two geotextiles or supported on a geomembrane and the bentonite is placed either in the form of power or granules. GCLs are generally installed over the compacted subgrade in the dry condition, and a cover soil is placed over it. GCLs imbibe moisture from the subgrade and cover soils after their installation and gets prehydrated, and the exact placement conditions (i.e. the dry unit weight and water content) and the exact compactive effort imparted to GCLs remains unknown. However, the amount of water imbibed by the GCLs depends on the water contents of the subgrade and cover soils, whereas the compaction energy imparted depends on the thickness of the cover soil placed above the GCLs, the capacity of the roller used and number of roller passes.

Previous research (by Daniel and Wu (1993) and other researches) on the compacted clay liners showed that the placement conditions play significant role on the performance of compacted clay liners. Daniel and Wu (1993) proposed an acceptable zone for the compacted clay liners, in terms of compaction dry unit weight and water content, based on the criteria of hydraulic conductivity, volume change and shear strength. As the basic constituent of GCLs is bentonite clay, the criteria applicable for the compacted clay liners should also hold good for the GCLs. However, as mentioned above, the GCLs are not compacted but some (unknown) amount of compaction energy is indirectly imparted to the GCLs at their field water content. Therefore, it is worth to understand the relevance of placement conditions on the behaviour of GCLs. Such studies are not available in the literature and will serve as an input for the development of the design guidelines.

The present study is carried out on the polypropylene fiber reinforced bentonite as the dynamic compaction may damage the GCLs and also the fiber reinforced bentonite closely represents the GCLs. Moreover, the thin layer of compacted fiber reinforced bentonite may serve as an alternative to the GCLs where the GCLs are not easily available. Further, the compacted fiber reinforced bentonite may also be used in conjunction with the GCLs for increasing the barrier thickness. Polypropylene fibers are cost effective, hydrophobic and unaffected by chemical and biological degradation, and can be obtained from recycling of plastic waste (Puppala and Musenda, 2000). Recent

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research on polypropylene fiber reinforced clay soil showed that the addition of fibers increased the compressive strength and reduced the tension cracking and swell-shrink potentials of compacted clays (Maher and Ho, 1994; Al Wahab and El-Kedrah, 1995; Nataraj and McManis, 1997; Ziegler et al., 1998; Miller and Rifai, 2004; Cai et al., 2006; Akbulut et al., 2007; Babu et al., 2008; Viswanadham et al., 2009; Falorca and Pinto, 2011; Tang et al., 2012; Olgun, 2013; Anagnostopoulos et al., 2014). Maher and Ho (1994), Miller and Rifai (2004) and Ple and Le (2012) reported that the hydraulic conductivity of fiber reinforced clay increased with the increase in fiber content. However, the research studies focused on hydraulic conductivity of polypropylene fiber reinforced bentonite for liner applications are limited. Moreover, the hydraulic conductivity of polypropylene fiber reinforced bentonite subjected to wetting and drying cycles is not known. Therefore, the present study establishes an acceptable zone, in terms of water content and dry unit weight, for polypropylene fiber reinforced bentonite based on the compacted state hydraulic conductivity, shrinkage and strength criteria. To achieve the aforementioned objective, series of laboratory tests were carried out on unreinforced and polypropylene fiber reinforced bentonite that include standard and modified Proctor compaction tests, shrinkage tests, hydraulic conductivity tests and unconfined compression strength tests. Further, the effect of cyclic wetting and drying on the hydraulic conductivity of fiber reinforced bentonite is also examined.

2. Materials

The commercially available bentonite at Chennai, India and polypropylene fibers of triangular cross section (length = 12 mm; effective diameter = 0.036 mm) were used in the present laboratory study. The properties of the bentonite were determined as per Indian standard specifications. The pH of the bentonite was determined using the standard method with a soil-water ratio of 1:2.5. The properties of bentonite and polypropylene fibers are tabulated in Tables 1 and 2, respectively.

3. Methods

3.1. Preparation of fiber reinforced bentonite mixture

Polypropylene fibers and bentonite were placed in alternative layers in a Hobart mixer bowl, and mixed at a speed of 62 rpm for about 8 min for obtaining the fiber reinforced bentonite mixture for laboratory testing (Fig. 1a; Model No. LM 17609, Lawrence and Mayo (India) Private Limited, Chennai, India). Based on the literature review, a fiber content of 3% by dry weight of bentonite was adopted for the present laboratory investigation (Setty and Rao, 1987; Setty and Murthy, 1990; Casagrande et al., 2006; Abdi et al., 2008; Ghazavi and Roustaie, 2010). The required quantity of fiber reinforced bentonite mixture/unreinforced bentonite was mixed with required volume of distilled water (with the aid of a sprayer and spatulas) to yield the desired water content and placed in polythene cover which in turn was placed in a desiccator for moisture equilibration for 3 days. The moisture equilibrated fiber reinforced bentonite/unreinforced bentonite was used for the preparation of specimens for the various tests described below.

Table 1
Properties of bentonite.

Property	Standard	Value
pH	IS 2720: Part 26	10.50
Natural moisture content, NMC (%)	IS 2720: Part 2	11.75
Liquid limit (%)	IS 2720: Part 5	396
Plastic limit (%)	IS 2720: Part 5	36
Shrinkage limit (%)	IS 2720: Part 6	7
Plasticity index (%)		360
Specific gravity, G_S	IS 2720: Part 3	2.72
Swell index (ml/2 g)	ASTM D5890	79
Grain size distribution (%)	IS 2720: Part 4	
Sand		3%
Silt		32%
Clay		65%
Unified soil classification		CH
Standard Proctor compaction characteristics	IS 2720: Part 7	
Maximum dry unit weight, γdmax (kN/m3)		12.77
Optimum moisture content, OMC (%)		34
Modified Proctor compaction characteristics	IS 2720: Part 8	
Maximum dry unit weight, γ_{dmax} (kN/m^3)		15.87
Optimum moisture content, OMC (%)		22.8

Table 2
Properties of polypropylene fibers (supplied by Reliance Industries Limited, India).

Property	Value
Shape	Triangular
pH	7.3
Specific gravity, G_f	0.91
Elastic modulus (MPa)	3500
Ignition temp (°C)	360
Melting point (%)	160–165
Elongation (%)	60–90
Water absorption	None
Solubility in water	Not soluble in water

3.2. Compaction and shrinkage tests

Both standard and modified Proctor compaction tests were carried out on both unreinforced bentonite and fiber reinforced bentonite. The compaction tests were carried out in compaction moulds of 100 mm diameter and 127.3 mm height as per IS 2720: Parts 7 and 8. The average values of two independent determinations are reported here.

Additional identical specimens (of unreinforced and fiber reinforced bentonite at different water contents) were prepared in the compaction moulds using both standard and modified Proctor compaction energies for tracing shrinkage behaviour from compacted state. The shrinkage behaviour of unreinforced and fiber reinforced bentonite specimens were traced by monitoring the weight and volume change of the specimens at regular intervals of time during drying. The specimens were dried initially at room temperature and subsequently at elevated temperatures of 45 and 110 °C in hot air oven. The vernier caliper (least count = 0.02 mm) was used for measuring the diameter and height of the specimens. The average values of diameter and height were used for the volume calculations. The shrinkage curves are presented in terms of void ratio-water content plots.

3.3. Unconfined compression tests

The required amount of moisture equilibrated unreinforced bentonite and fiber reinforced bentonite were placed in moulds of 38 mm diameter and statically compacted (height = 76 mm) to the desired dry unit weight. The specimens were sheared at a strain rate of 0.8%/min in a triaxial frame. The peak stress values are reported as the unconfined compressive strength of the specimens.

3.4. Hydraulic conductivity tests

The required amount of moisture equilibrated unreinforced bentonite and fiber reinforced bentonite were transferred to separate oedometer rings (diameter = 76 mm; height = 30 mm) and statically compacted (specimen height = 14 ± 0.5 mm) to the desired dry unit weight and setup in separate oedometer assemblies. A surcharge

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