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A COMPERATIVE STUDY OF FIBER REINFORCED SOIL LINERS

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Abstract: Environmental authorities are always concerned about disposal of industrial waste. Studies suggest that landfill is the most suitable ways for disposing of these wastes. Compacted clay liners and geosynthetic clay liners are commonly used .But various atmospheric conditions such as drying and wetting cause changes in the clay structure. The changes occur mainly in the form of desiccation cracks. Through these cracks leachate gets permeated. This in turn results in environmental pollution and also reduces the compatibility of liner system. Many studies suggest that addition of additives have reduced the cracks in soil but this alters the physical behavior of clay. Hence the technique of fiber reinforcement was adopted. In this study natural and synthetic fibers such as polypropylene and straw were used to reduce the desiccation cracks in soil. The fibers were amended to soil in 0.2%, 0.4%, 0.6%&0.8 % of dry weight. Fiber reinforcement to soil improves the properties of liner. Hydraulic conductivity increases with fiber reinforcement and was within acceptable limits for that of a landfill liner.
Keywords: compacted clay liners, desiccation cracks, fiber reinforcement, polypropylene, hydraulic conductivity

1. Introduction

Urbanization is progressing at an alarming rate resulting in the generation of very large quantities of municipal solid waste. Collection and disposal of municipal solid waste are one of the key service concerns faced by civic bodies. The quantity of solid waste generated, the scarce availability of land and the pollution caused to the soil and groundwater makes the management of municipal solid waste a major challenge in a dense urban environment. One of the preferred methods of dealing with this kind of environmental problem is to dispose of the waste in sanitary landfills. Solid waste undergoes physico-chemical and biological changes. Consequently, the degradation of the organic fraction of the wastes in combination with percolating rainwater leads to the generation of a highly contaminated liquid called “leachate”. To prevent contamination of the surrounding soil and underlying groundwater by leachate, landfills are lined and covered with an impermeable material. Compacted clayey soils or geosynthetic clay liners (GCLs) are predominantly used in the construction of landfill liners. The main reason in using such materials is their low hydraulic conductivity which limits or eliminates the movement of not only the leachate from bottom of landfills but also the generated gases from the final cap of waste dumps.

Clayey soils possess numerous problems to geotechnical engineers because of their high compressibility and poor shear strength. The high compressibility of clays which leads to large scale volume changes is always a cause of concern to the field engineer. Volume changes in clayey soils occur in many ways. One is due to the expulsion of pore water from the voids upon static surcharge. This behavior, termed as consolidation is a well known and well defined phenomenon. The other volume change is due to the shrinking of clay soils during drying. Desiccation is the continuous process of pore water loss from a soil exposed to a warm environment. In response to drying, soil water volume decreases and in consequence the soil shrinks. The desiccation cracking of clay mass can have a significant impact on the performance of clayey soils in various geotechnical, agricultural and environmental applications. Cracks affect the compressibility of the soil, its time rate of consolidation, its strength and the rate at which water can re-enter. Thus, several geotechnical constructions are affected directly or indirectly by the presence of cracks in a soil mass. Desiccation cracking is a common phenomenon in clayey soils and can change the hydraulic conductivity of soil. Compacted clay liners are essential components of both municipal and hazardous waste landfills and their design has typically been based on the premise that little leakage will occur if the soil has a laboratory measured hydraulic conductivity of less than $1x10^{-9}$m/s. Hydraulic conductivity of clay liner material may increase from $1x10^{-9}$m/s for wet and intact soil, to $1x10^{-6}$m/s for the material after cracking.

A variety of research efforts have attempted to address the problem of desiccation cracking. Some have considered the use of surface moisture barrier above the clay liner, but case histories show that repeated cycles with seasonal temperature changes result in significant desiccation of the clay layer and associated cracking. Many researchers have also used lime, cement and sand as additive to reduce the desiccation cracking in compacted clay .The reports suggest that soil shrinkage reduced and its hydraulic conductivity increased in some cases. Because of short coming of the materials and due to above drawbacks an attempt is therefore made here to conduct a comparative study to control the desiccation cracks by using different randomly distributed discrete fibers. The main advantage of reinforcement of soil with fibers is the absence of single potential plane of failure compared to conventional Geosynthetic sheet. Fiber reinforcement improves the strength properties of the soil that is subjected to various stresses.

2. Previous Research

Arif Ali et.al (2016) conducted experiment on lime treated expansive soil to be used in liner .Polypropylene fibers of mesh type and cast type in two different lengths were used in the study. He observed that the hydraulic conductivity was least for fibers of short in length and mesh type. The soil is treated with lime so as to ensure a bonding with clay and fiber. It was also observed that increasing curing period of fiber reinforced sample decreases hydraulic conductivity.

Umachaduvala et.al (2016) conducted experiment with polyester fibers used as geofibers in order to reinforce the expansive soil specimen .The digital image Acquisition System (DIAS), which consisted of a digital camera, was employed to capture images of drying soil with and without fibers. Fiber reinforcement significantly alters the crack morphology. The crack patterns in unreinforced soil are uniform, long, and thick. The crack patterns in the case of fiber reinforced soil had low crack intensity because they were non-uniform, small, rough .Fibers of longer lengths were found to be inefficient in restraining desiccation

Jun He et.al (2015) studied the hydraulic conductivities of natural clay and bentonite-modified clay with and without desiccation cracks were measured. Three types of liquids as permeating liquid: 2500 mg/L acetic acid solution, 0.5 mol/L $CaCl_2$ solution, and tap water. When tap water was adopted as the permeating liquid, desiccation cracks resulted in increases in the average value of hydraulic conductivity: a 25-fold increase for the natural clay and a 5.7-fold increase for the bentonite-modified clay. It was also found out that the strong self-healing capability of bentonite helped to reduce the adverse impact of cracks on hydraulic performance. In contrast to tap water, simulated leachates (acetic acid and CaCl2 solutions) show no adverse effect on the hydraulic conductivities of natural and bentonite-modified clays. It is concluded that desiccation cracks and bentonite have more significant effects on hydraulic performance than simulated leachates.

Venkat Bhadriraju et.al (2015) carried experiment on carbon fibers mixed at dosages computed based on weight of the dry soil. There was a decrease in the dry unit weight and a simultaneous increase in the optimum moisture content with increasing fiber dosages. The influence of fibers on dry unit weight and optimum moisture contents has been consistent for all three types of fibers used in this research. All the fibers were found effective in minimizing shrinkage of the expansive soil. Carbon fibers were found to be the most effective when compared to other fibers. This may be due to relatively high tensile strength

Miller et.al (2008) Fiber intrusion impacted both optimum moisture content and dry density .The maximum dry density increased up to 0.8% fiber content for light compaction test .Crack intensity factor is defined as percentage cracked area to total surface area of sample .The fiber intrusion reduced the crack up to 90% .But the hydraulic conductivity of the amended sample increased But 0.5% maintained hydraulic conductivity with acceptable limits

Mahmood R. Abdi (2008) investigated the effects of random fiber inclusion on consolidation settlement, hydraulic conductivity, swelling, shrinkage limit and desiccation cracking characteristics of clay. Investigations showed that there is a maximum fiber content and length that can be used because of workability problems making uniform mixing of fibers with soil were very difficult. In this investigation the maximum fiber content and length determined were 8% and 15mm respectively. The addition of randomly distributed polypropylene fibers resulted in substantially reducing the consolidation settlement of the clay soil. Length of fibers had an insignificant effect on this soil characteristic, whereas fiber contents proved more influential and effective. Inclusion of polypropylene fibers to the clay soil resulted in reducing the amount of swelling after unloading. The effect was proportional to the fiber content. But at constant fiber contents, the amount of swelling was not significantly affected by increasing fiber length. Hydraulic conductivity of the clay soil due to random inclusion of fibers was slightly increased as function of both fiber content and length. However, the overall increase was not so significant to render the soil unsuitable for use as liner or cover in landfills. For all the fiber contents and lengths investigated, the hydraulic conductivities measured (i.e.10^{-9} cm/s) were well below the minimum requirement of 10^{-7}cm/s according to USEPA.

Sobha Cyrus (2008) conducted studies on the development and control of desiccation cracks in compacted clay liner soils. She conducted studies on three type of soil and and amending these with three types of fibers, namely nylon fiber, polypropylene monofilament and polypropylene fiber. The results showed that there is definite improvement in the properties of the liner materials when it is reinforced with discrete random fibers. The study also proved that the desiccation cracks could be controlled with the help of fiber reinforcement.

3. Materials and Methodology

3.1 Materials

3.1.1 Soil

This soil was collected from a paddy field Aloor Thrissur. Preliminary testing revealed that the soil was CH classification. Disturbed samples were collected at a depth 1.5 m below the ground. Physical properties of soil are tabulated in Table 1.

Table 1: Properties of soil

Sl. No	Properties	Values
1	Initial water content (%)	19.00
2	Specific gravity	2.61
3	Particle size distribution 1) Gravel(%) 2) Sand (%) 3) Silt (%) 4) Clay (%)	 2.00 19.00 38.00 41.00
4	Free swell index (%)	40.00
5	Liquid Limit (%)	52.00
6	Plastic Limit (%)	22.00
7	Plasticity Index (%)	30.00
8	Shrinkage Limit (%)	12.5
9	Maximum Dry Density (kN/m^3)	17
10	Optimum moisture content (%)	22
11	Unconfined Compressive Strength (kN/m^2)	189
12	IS classification	CH

3.1.2 Polypropylene fiber

Clay liner has serious limitations, due to development of cracks on desiccation. Attempts were made to effectively control this. The cracks were controlled by reinforcing the soil with the help of randomly distributed discrete fibers. Polypropylene is the most common synthetic material used to reinforce concrete and soil. The primary attraction of this material is it's relatively low cost. It easily mixes with soil and has a relatively high melting point which makes it possible to place the specimens of the fibrous soil in the oven and conduct the tests for moisture content. Also, polypropylene is hydrophobic and it is unaffected by the presence of salts in soil or by biological and ultraviolet degradation. These properties of polypropylene make it an excellent fiber that can be used in clay liners. Virgin triangular polypropylene fibers were used in the study. The fibers were provided by Neptune Ready mix concrete pvt limited, Kochi. The properties of the fiber were given in table 2.

Figure 1: Polypropylene fiber

3.1.3 Straw fiber

Many studies have proven that straw fibers were used a binding material in various constructions. Straw mats are used to control erosion. During growth, rice plants absorb silica from the soil and accumulate it into their structures. It is this silica that imparts tensile strength when used for reinforcement. Being a natural fiber these are considered eco-friendly .Besides this they are easily available and is cheaper than any other fiber. For conducting the study the straw fiber was collected from Thrissur. The raw straw fibers were extracted by alkaline soaking .The impurities such as leaves, joints were removed from straw. The treated straw fibers were then cut into small lengths and were kept in polythene bags. The resulted rougher surface of the fibers after treatment provides better mechanical interlocking hence stronger interfacial strength between them.

Figure 2: Straw fiber before treatment

Figure3: Straw fiber after treatment

Table 2: Properties of polypropylene and straw fiber

Properties	**Polypropylene**	**Straw**
Length	12mm	12mm
Diameter	.028	.020-.050

3.2 Methodology

The properties of soil selected for this study was determined in the laboratory according to the relevant I.S. code (IS 2720). Fibers were added to soil in 0.2%, 0.4%, 0.6%, and 0.8% of dry weight of soil and geotechnical properties were determined.

4. Results and Discussion

4.1 Atterberg limits (IS 2720: part V & VI)

4.1.1 Liquid limit (LL)

The result shows the effect of varying percentages of fiber on the liquid limits of selected soil sample. The liquid limit decreases with increasing the percentage of fiber. This is due to reduction in the specific surface area of the soil.

4.1.2 Plastic limit (PL)

The results show variation of plastic limit with the addition of fiber. There is an increase in plastic limit with increase in percentage of fiber

4.1.3 Plasticity index (PI)

The results show variation of plasticity index with the addition of fiber. There is a decrease in plasticity index with increase in percentage of fiber

4.1.4 Shrinkage limit (SL)

The results show variation of shrinkage limit with the addition of fiber. There is an increase in shrinkage limit with increase in percentage of fiber. Increase in the shrinkage limits means that fibers having greater surface contacts with the soil have shown greater resistance to volume change on desiccation.

The variations in Liquid limit, Plastic limit, Plasticity index and shrinkage limit are shown in the figure 4, 5, 6&7.

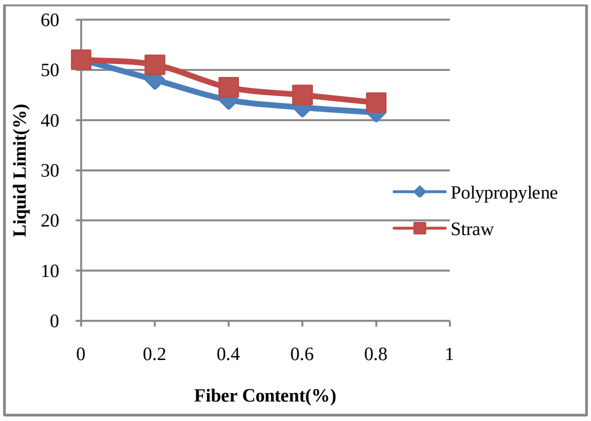

Figure 4: Variation of liquid limits with addition of polypropylene and straw fiber

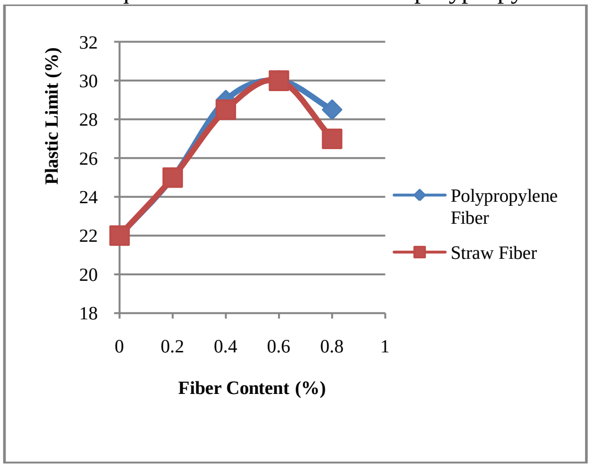

Figure 5: Variation of plastc limit with addition of polypropylene and straw fiber

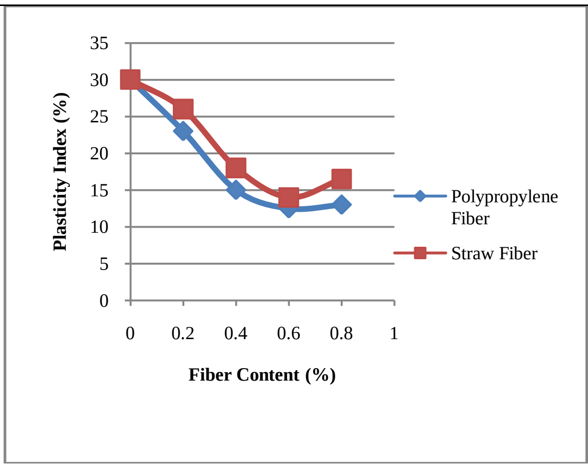

Figure6: Variation of plasticity index with addition of polypropylene and straw fiber

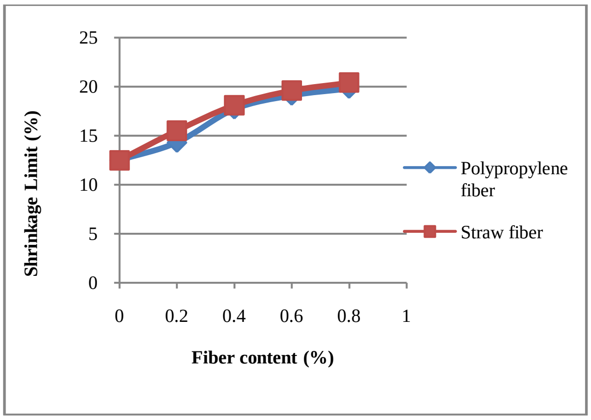

Figure 7: Variation of shrinkage limit with addition of polypropylene and straw fiber

Figure 4: Variation of OMC and MDD with addition of fiber

4.2 Unconfined Compressive Strength of Soil (IS 2720: Part X, 1991)

The Unconfined compressive strength of polypropylene and straw fiber amended soil was shown in figure8. UCS values increased with increased percentage of fiber upto optimum value and then shows decreasing trend with further addition. Maximum strength is obtained at 0.6% polypropylene fiber and 0.4% for straw fiber. The increase in UCS value is due to the tensile strength imparted by fiber in to soil. Both fiber increase the resistance between soil particles and improves stiffness and ductility.

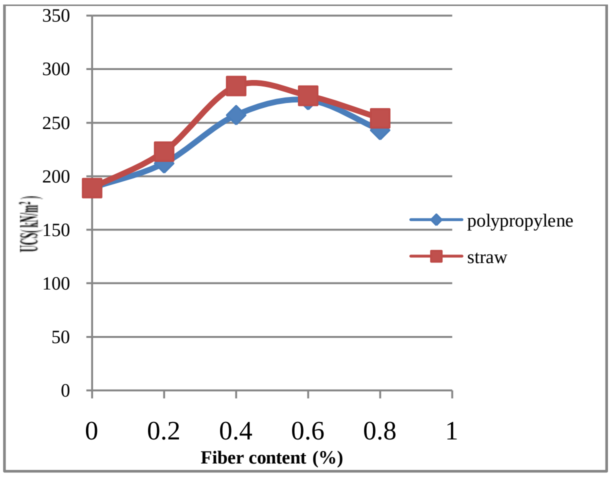

Figure 8: Variation of UCS with addition of Polypropylene and straw fiber

4.3 Consolidation Test (IS 2720: part-XV, 1986)

In order to determine the effects of fiber inclusion on hydraulic conductivity consolidation test was conducted **.**both polypropylene and straw fibers were amended to soil at 0.2%, 0.4%, 0.6% and 0.8%. The hydraulic conductivity increased with increase in fiber content in case of both fibers .The increase in hydraulic conductivity is mainly because the fibers act as water conduits thus by increasing flow .But the obtained values still satisfies the liner requirement of less than 1 x 10^{-9} m/s.The results were shown in figure 9.

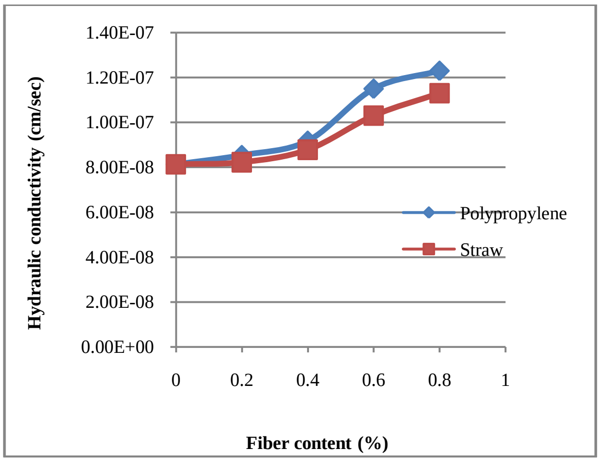

Figure 9: Variation of hydraulic conductivity with addition of polypropylene and straw fiber

4.4 Desiccation Cracking

In order to analyze the desiccation cracks samples were prepared in circular mould and were used for observational examination of the extent of cracking. From the observational studies it was seen that reinforcing with polypropylene and straw fibers the extent of desiccation cracks were reduced .The main reason behind this is the tensile strength imparted by fiber to soil which effectively suppress cracking .At 0.6% polypropylene almost all the cracks were reduced .In case of straw fiber reinforcement, at 0.4% fiber content the extent of cracking get reduced. Figure10. Shows surface cracking features of both fiber amended soil.

Figure 10) a. Surface cracking feature of 0% fiber

Figure 10) b. Surface cracking feature of 0.6% polypropylene fiber

Figure 10) c. Surface cracking feature of 0.4% Straw fiber

Deep and wide cracks were formed on unreinforced specimen .The reinforced sample shows reduction in cracks .In case of polypropylene reinforced soil at0.6% almost all cracks were sealed and for straw fiber it was 0.4%.

5. Conclusions

In the current study the fiber reinforcement technique affected unconfined compressive strength,hydraulic conductivity and desiccation cracking of soil .Fiber has the ablity to impart tensile strength to the soil thus reduce the formation of cracks. It can be concluded that addition of fiber has improved the following soil properties considerably:

- PI decreased for fiber amended soil
- SL increased for both fiber amended soil and the increase is more for straw fibewr amended soil
- Hydraulic conductivity of clay soil due to random inclusion of fiber was slightly increased as a function of fiber content. However the increment was within limits satisfied by liner.
- Desiccation cracking of clay soil due to random inclusion of fiber reduced to great extent .The depth of cracks was more for unreinforced specimen compared to reinforced sample.

The overall results suggest the use of fiber additives for a landfill liner to improve the durability of system.

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