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A Comprehensive Review of New Trends in the Use of Geosynthetics Clay Liner GCLs in Landfill

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Abstract: Open dumping sites are what most dumps in developing countries often known as landfills are called because they lack a liner, a drainage layer, and adequate cover. If not managed effectively, landfills may contaminate surface water and groundwater via leachate intrusion into land and aquifers. The resulting leachate poses a serious threat to human health and the environment due to its constituents' toxic and tenacious nature. Waste containment facilities are one of the geotechnical systems that use the most geosynthetic kinds for all purposes. There will likely be an uptick in the usage of geosynthetic components as companies innovate and produce better materials and engineers/designers create analytical algorithms for novel applications. In this study, we provide the key results, emphasizing the critical factors determining Geosynthetic Clay Liners (GCLs) service life. The design implications of using GCLs are also discussed, giving the reader a broad perspective.

Keywords: *Landfill; Geosynthetic clay liner; review; Bentonite; Hydraulic conductivity*

1. Introduction

For environmental containment purposes, engineers create geosynthetic clay liners (GCLs) out of geotextile and bentonite composites (usually sodium bentonite sandwiched between two layers of geotextile). Long-lasting protection against physical or chemical breakdown in severe environments is provided by geotextiles, while bentonite's high swelling capacity and low permeability provide an efficient hydraulic seal. By exchanging the bulk of the compacted clay for a thin coating of pure sodium bentonite, GCLs are a great alternative to compacted clay liners (CCLs). The advantages include quick assembly, enhanced hydraulic performance, and resilience to climate swings. Most importantly, GCL projects may have their installations done by regular construction crews and tools. Because of their self-sealing properties, GCLs are less likely to fail under demanding operating and field circumstances. Their use originated in geotechnical engineering but has advanced greatly as new materials and variants of the fundamental geosynthetics have become available. This article will briefly overview the most significant discoveries from the previous decade of study on geosynthetic clay liners (GCLs) and how their performance might be affected by their interactions with their environments [1][2].

Closed landfills nowadays cannot function without a barrier system. In the 1980s, compacted clay liner was often used as part of a landfill's barrier system (CCL). Geomembrane (G.M.) gradually replaced this by the late 1980s. The GCL (geosynthetic clay liner) composite liner system has been widely used since the 1990s. Bentonite is the main component of the geosynthetic clay liner, which is then surrounded by geotextiles or geomembranes. GCLs have several benefits over compacted clay liners and geomembranes, including low hydraulic conductivity, improved mechanical behavior, and easy and speedy installation in the field. In addition, GCL's high swelling capacity because of the bentonite employed in it allows for local damage caused by field installation to self-heal in certain cases.

As a result of these features, GCLs have been widely adopted for use in a variety of geotechnical applications [3-12], such as dams, artificial lakes, sewage-treatment ponds, storage tanks, landfills, polluted regions, and so on. An extensive study of GCL and bentonite-based barriers' physical and mechanical properties for environmental purposes has been conducted over the last three decades [13-19]. Most studies have focused on the following characteristics of GCLs: (i) hydraulic conductivity and chemical compatibility; (ii) self-healing capabilities; (iii) diffusion; (iv) gas migration; and (v) mechanical behaviors, such as creep behavior [20]. There is a direct relationship between these characteristics and the shape and mineralogy of bentonite, both of which have gotten a lot of study in recent years. Additionally, due to their expanding use in mining and industrial operations, several studies have been conducted to assess the impact of exposure to harsh environments and conditions on GCL materials (e.g., heap leach pads,

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etc.)., heap leach pads, for instance, Examples: very low temperatures, extremely high temperatures, extremely high salinity, extremely acidic or alkaline conditions, etc.). Few studies have focused on mining applications and, more specifically, how the bentonites may respond hydraulically to leachates having extreme pH levels (i.e. pH 3 and pH >12). Even though GCLs have been extensively studied in recent years to determine the effect of various chemical solutions (mostly including inorganic salt or organic chemical solutions) on their hydraulic performance. For this reason, studies focusing on bentonite modifications became more popular as a means of mitigating these impacts. Polymer-treated bentonites are a common new ingredient in GCLs [23-25]. This paper's goals are twofold: to present a complete account of the primary discoveries on the five features above of GCLs during the last several decades and to propose possibilities for additional investigations.

2. Background

For a better understanding of Geosynthetic Clay Liners (GCLs), it is helpful to first break down its constituent parts. Bentonite clay layers (GCLs) are composite materials made of bentonite clay that are layered inside or atop geotextiles or geomembranes. It is crucial to highlight that GCLs have had different designations in the past and even now for context, even though the International Standards Organization (ISO) currently refers to them as Geosynthetic Barriers-Clay (GBR-C) [26][27].

2.1 Bentonite

Bentonite is well-known in the industry as clay with low permeability to both liquids and gases [28-30]. When compared to other naturally occurring geologic materials, sodium bentonite has the lowest permeability that we are aware of [31-38]. Only wholesale quantities are on hand. Shipping bentonite from these areas to GCL companies throughout the globe is an expensive endeavor. Alternatively, calcium bentonite with better permeability may be found in plentiful natural deposits across the globe. When calcium bentonite is treated with sodium hydroxide, the calcium ions are replaced by sodium ions, reducing the material's permeability to that of natural sodium bentonite. This method, which is used all around the globe, is frequently referred to as "peptizing." Although it has not taken hold, I expect this tendency to grow in the coming years. X-ray diffraction is a reliable technique for evaluating the chemical makeup of clays, making it ideal for identifying bentonite. However, not many labs can do the test because of the high cost and limited availability of geosynthetics testing equipment. The methylene blue analysis used by the American Petroleum Institute is straightforward and generally accepted to provide conservative findings, although it is not as accurate as other methods. It is believed that a montmorillonite content of at least 70% is necessary to give appropriate swell and permeability readings for usage in GCLs when employing such a test. This number is close to the 90% value obtained by the X-ray diffraction [39]. Bentonite qualities are covered in further detail in [40].

2.2 Geotextiles

As the carrier material underneath the bentonite and the cap (or cover) fabric above it, geotextiles are often used. It is possible to create geotextiles using a combination of nonwoven and woven scrim or from woven materials alone. The great majority of geotextiles are made from polypropylene resins with various additives such as high-temperature processing aids, U.V. light stabilizers, and long-term durability additives. Woven geotextiles, such as slit film or spin laced, offer great strength and stiffness qualities, but their weave must be tight enough to prevent bentonite from seeping through. The geotextiles' inherent qualities should not be disregarded. In addition to aperture size, other critical parameters include tensile strength, tensile elongation, and installation survival [41].

2.3 Geomembranes

Is a synthetic membrane liner or barrier with extremely low permeability used to manage fluid (or gas) movement in an artificial setup [42]. Now that we know how dangerous polluted ground is to buildings and ecosystems, membranes are used more often in civil and environmental applications such as landfills. Adhering bentonite to a geomembrane because of this, the glue must be mixed in with the bentonite before use. In the thickness range of 1 mm to 1.5 mm, textured high-density polyethylene (HDPE) geomembranes are widely used. There are three different methods to set up this product. There are three possible configurations of the geomembrane and bentonite layers: geomembrane on top; bentonite below; geomembrane on top; bentonite below; geomembrane on top of the bentonite as a protective layer.

2.4. Hydraulic conductivity and chemical compatibility

The hydraulic conductivity of bentonite determines the extent to which GCLs may function as hydraulic systems. However, GCLs with a geomembrane seamed during construction are an exception to this rule (e.g., with a cap strip). The hydraulic conductivity to the water of geotextile-supported GCLs, measured in a laboratory, varies from around 21012 m/s to 21010 m/s, depending on the degree of confining force that is applied (Figure 1). The drop in GCL hydraulic conductivity was attributed by [43] to lower bulk void ratios resulting from increasing confining pressures. Moreover, they showed that for a given permeant, the bulk void ratio correlates strongly with the hydraulic conductivity, k. Since GCLs are often used to hold liquids other than water, the evaluation of the hydraulic conductivity of GCLs when acted upon by chemical solutions is of the highest importance. Immersion of the specimen in the permeant liquid or a liquid selected to replicate it is the gold standard for compatibility testing closely. This measures the material's hydraulic conductivity compared to a true permeability liquid. Several academics and efforts have studied the GCL's compatibility with various permeants [13] [28] [43-50]. A GCL's hydraulic conductivity with non-water liquids is affected by several parameters, including aggregate size, montmorillonite concentration, adsorbed layer thickness, hydration, and void ratio of the mineral component.

Alternatively, the hydraulic conductivity is mostly determined by the concentration of monovalent and divalent cations in the permeant. The chemical composition of the permeant influent and effluent must be monitored during these tests, as well as the passage of sufficient pore volumes of the permeant through the sample to ensure chemical equilibrium. It is also recommended that the GCL height be maintained while these tests are conducted. The difficulties of maintaining chemical compatibility with GCLs are detailed in [13][49]. Without a liquid medium like water, pollutants may travel from high- to low-concentration zones via a chemical process known as diffusion. Two recent studies [49][51] detail how inorganic contaminants move across a GCL by diffusion. The main findings from their study are as follows: Changes in the microstructure of the sensitive mineral component are directly related to the diffusion coefficient, and the coefficient fluctuates dramatically with solute concentration (in particular sodium bentonite). However, the production of GCLs had little effect on the diffusion coefficient.

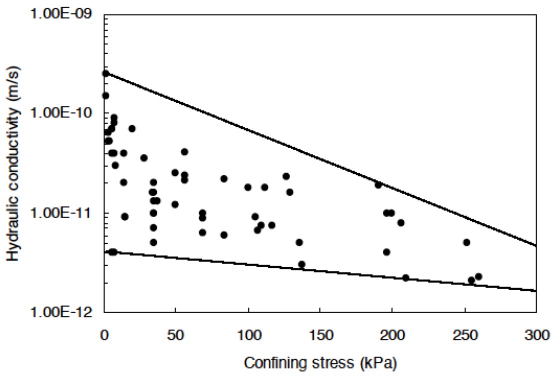

Fig. 1 Changes in Confining Pressure and Hydraulic Conductivity (results compiled from various sources)

2.5 GCL manufacturing

Non-reinforced and (internally) reinforced GCLs are presently the only two structurally distinct forms of GCLs currently available. Hydrated bentonite has a very low shear strength, which led to the development of the two forms. GCLs with needle punching or stitch bonding are employed on steep slopes, whilst nonreinforced GCLs are used on flat terrain. There are several subtypes of each class. Geotextile, geotextile/polymer, or geomembrane are all subcategories of nonreinforced GCLs. As seen in Figure 2a, the geotextile-related varieties have geotextiles on both sides and an adhesive combined with bentonite for bonding. The geotextile/polymer kinds are related, but the top geotextile is impregnated with a polymer to reduce permeability below the bentonite itself. As a result, the bentonites are affixed to the geomembrane (see Figure 2b). Any kind, thickness, or surface texture of the geomembrane may be used. Reinforced GCLs, on the other hand, are much more prevalent. Table 1 summarizes the benefits and drawbacks of GCLs. Because of the increasing scope of GCL use comes an increased need for in-depth research into such aspects as hydraulic and diffusion properties, compatibility with chemicals, mechanical behavior, durability, and gas migration [13][29][30][43] [47][51-55].

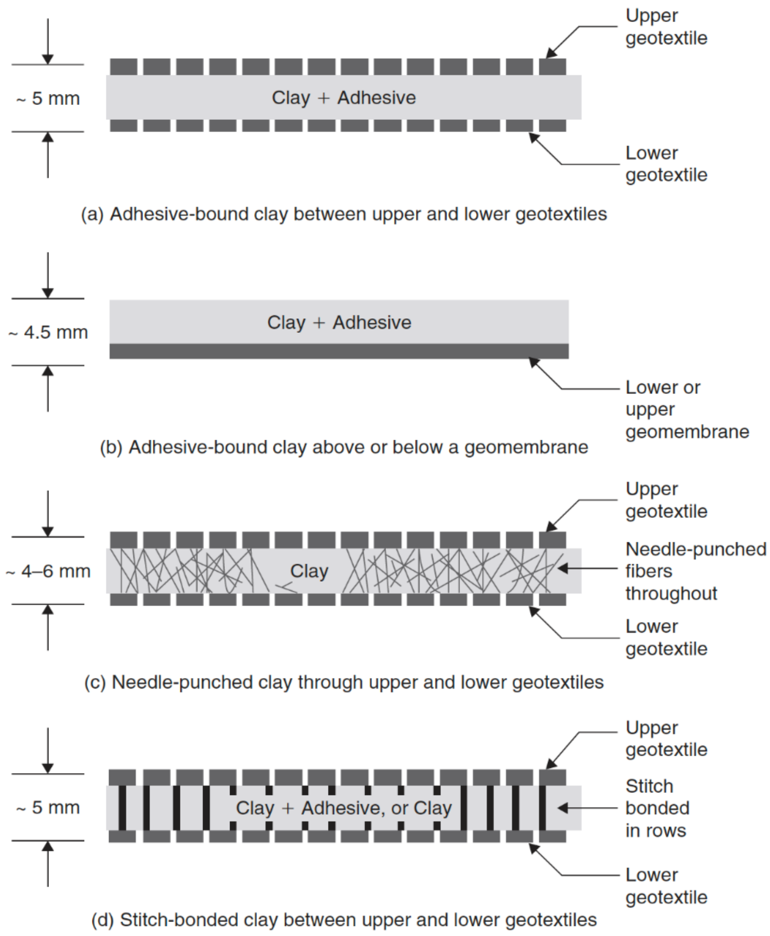

Fig. 2 Cross Section of Currently Available GCLs, After [56].

Table 1- Advantages and disadvantages of GCLs [13][57]

Advantages	Disadvantages
Quick setup with fewer experienced workers and lower costs.	Shear strength is low for bentonite once it has been hydrated (for unreinforced GCLs).
If built correctly, it has low hydraulic conductivity to the water.	GCLs may be pierced either before or after they are set up.
Capable of withstanding significant differential settling.	The risk of bentonite spillage during installation.
Good capacity for self-repair.	This gas-permeable low-moisture bentonite.
Lacking reliance on the availability of regional soils.	Possible weak spots in material interactions.
It is simple to fix.	Leachate attenuation capability is decreased.
Ability to withstand the effects of freezing and thawing.	Shear strength may decrease after the peak.
More air may get through because of the reduced thickness.	Potentially increased long-term flux as a result of decreased bentonite thickness in response to applied normal stress.

Testing hydraulic conductivity in the field is unnecessary.	If not prehydrated with an appropriate water source, a possible rise in hydraulic conductivity might result from compatibility issues with the pollutant.
The gas-barrier properties of hydrated GCL	Increased pollutant diffusive flux compared to that of compacted clay liners.
Lighten the load on compressible substrates (MSW).	Ion exchange is vulnerable (in the case of sodium bentonite in GCLs)
	In danger of drying out if not well covered (with at least 0.6m of soil).

3. Conclusions

Geosynthetic clay liners have gained widespread use in recent decades, either as a direct substitute for compacted clay liners in cover systems or as an additional layer underneath landfill bottom liners. This paper provides a thorough evaluation of the previous studies conducted on these liners. From what we can see, they retain their hydraulic integrity well over time and have a very low hydraulic conductivity to thewater. Concerns about chemical compatibility issues, penetration, and localized loss of bentonite, bentonite thinning, piping phenomena, and ion exchange, well as their potential influence on the GCL's hydraulic integrity throughout the course of its service life have attracted a lot of attention in recent years. Because of their widespread use in mining and industry, GCL materials have also been the subject of a great deal of research into the effects of prolonged exposure to extreme environments and circumstances (e.g., heap leach pads, etc.). (Heap leach pads, for instance) (Examples: Extreme Cold, Heat, Hyper-Salinity, Acidic, Alkaline, etc.). It seems that the kind and moisture level of the GCL has a role in this. When large vertical settlements are anticipated, GCLs are acceptable or recommended for usage, as well as for landfill capping, where pressures are lower, and a great deal of flexibility is needed.

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