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The New Generation of GEOSYNTHETIC CLAY LINERS

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The New Generation of GEOSYNTHETIC CLAY LINERS

1. Introduction

A Geosynthetic Clay Liner (GCL) is according to ASTM D 4439 a manufactured hydraulic barrier consisting of clay bonded to a layer or layers of geosynthetic materials. A GCL is also known as a bentonite liner, bentonite mat, or according to the latest published ISO 10318 standard a Clay Geosynthetic Barrier (GBR-C). A recently published document from the Geosynthetic Research Institute, Folsom, Philadelphia (2005) GRI-GCL3 "Standard Specification for Test Methods, Required Properties, and Testing Frequencies of Geosynthetic Clay Liners (GCLs)" divides the GCLs into two groups, the unreinforced and reinforced GCLs. One type of reinforcing GCLs is needlepunching. Hereby a set quantity of high swelling sodium bentonite is confined between two geotextiles and the geotextiles are then needlepunched together through the intermediate bentonite layer (fig. 1), securing the bentonite in place and reinforcing the otherwise weak layer of clay (when hydrated). The carrier layer is either a woven or a combination woven/nonwoven geotextile which allows for good anchorage of fibres. (von MAUBEUGE et al., 2007) The main purpose of a geosynthetic clay liner (GCL) is to reduce/limit the flow of liquid through the GCL or barrier system. GCLs are mostly used to replace a compacted clay liner (CCL) or soil barrier. High swelling sodium bentonite typically acts as the primary sealing element. In many applications GCLs are used as single barrier, whereas in other applications, such as in municipal solid waste landfills, GCLs are also used in combination with a geomembrane.

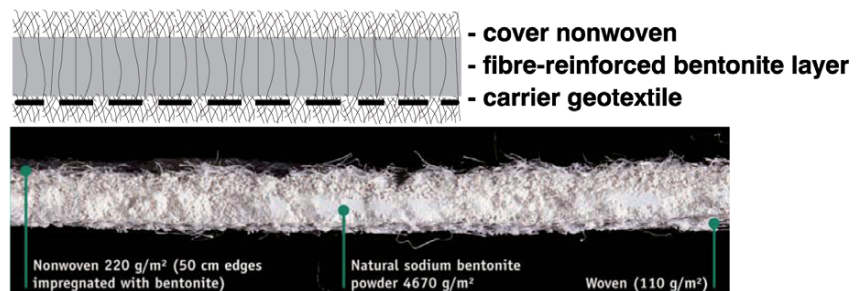


Fig. 1 Needlepunched GCL cross-section

2. Typical Advantages of Needle punched GCLs

Needlepunched geosynthetic clay liners (GCLs) are fibre-reinforced composites that combine two durable outer layers and an intermediate, uniform core of high-swelling powder sodium bentonite clay. This unique clay core acts as the barrier component, but its ultimate performance is dependent upon the durability and security provided by the outer layers.

The uniform needlepunching forms a directionally independent, shear strength transferring sealing barrier. When the bentonite core hydrates with fresh water, the bentonite swells and forms a low-permeability gel layer, which outperforms traditional, thick compacted clay liners, due to the bentonite's ability to self-seal and re-heal.

Other features of needlepunched GCLs are sometime product dependent and include (but are not limited to):

- High internal shear strength for steeper slopes
- Durable geotextiles for the encapsulation of bentonite and long-term performance
- Excellent interface friction values
- Robust against installation strength (if the nonwoven of the GCL is placed against cover soil material)
- Powder bentonite for uniform clay distribution and immediate swelling. This high-quality powdered form of bentonite ensures a better seal and longer-term performance than granulated bentonite.
- Self-sealing of bentonite-impregnated overlaps

3. Multicomponent GCLs

In 1987, a worldwide supplying major German geosynthetic manufacturer invented the first needlepunching method of GCL manufacturing and was awarded various patents and awards. It was the first in a series of innovations that have not only expanded the range of applications for which GCLs can be used but have contributed greatly to the overall field's understanding of GCL performance. Needlepunching vastly increased the shear strength of GCLs. Next, the German inventor of needlepunched GCLs created a proprietary heat-treating process known as thermal lock, which further improved the internal shear resistance. Another step towards the GCL improvement was the bentonite impregnation of the cover nonwoven component during the manufacturing process, ensuring the self-sealing properties of the bentonite-treated overlaps. Most recently, multicomponent GCLs are introduced to the market. Either a thin plastic barrier is attached to one geotextile component of the GCL or a durable polyolefin polymer is firmly coated to the slit-film woven geotextile component of the GCL. This development enables GCLs to challenge particular site conditions where the use of GCLs has previously been limited.

The following definition proposals are currently being discussed in the ASTM D35 terminology task group and might be added in future in the ASTM terminology standard D4439.

multicomponent GCL, n - GCL with an attached film, coating, or membrane decreasing the hydraulic conductivity or protecting the clay core or both

adhered geosynthetic clay liner (GCL), n - GCL product in which the clay component is bonded to a film or membrane by adhesion

coated GCL, n - GCL product with at least one layer of a synthetic substance applied to the GCL as a fluid and allowed to solidify

4. Applications for Polymer Coated Multicomponent GCLs

In general, polymer coated, needlepunched GCLs can be used in all applications (table 1) where long-term sealing barriers are requested. The polymer coated GCL is most effective, though, when at least one of the described advantages listed in section 5 and 7 is an important design criterion.

Application	Design Issues		
	hydraulic head	rooting	ion exchange
Ponds (fig. 2)	hydraulic head	rooting	ion exchange
waterways	hydraulic head	rooting	desiccation
landfills	roots	gas permeation	ion exchange
Waterproofing - underground structures (fig. 3)	gas permeation		
tank farms (e.g., fuel depots)	roots	barrier against critical liquids	desiccation
mining	desiccation	additional barrier against critical liquids	ion exchange
roads and railways	desiccation	roots	ion exchange
canals/levees	hydraulic head	roots	

Table 1: Important design issues, where multicomponent GCLs have an add-on effect to the GCL performance



Figure 2: Pond being sealed with a needlepunched and coated GCL



Figure 3: Underground waterproofing sealed with a needlepunched and coated GCL

5. Advantages of the Coated Multicomponent GCLs

The success of needlepunched GCLs has been proven in approximately 100 million square meters of installed material since 1987. In this time, a worldwide supplying major German geosynthetic and GCL manufacturer has sought continually to improve the internal shear strength of needlepunched GCLs to achieve ever-better ecological, economical and performance-related benefits for engineers. Further innovations have also been pursued with the outer layers of the GCL. The polymer coating option of a new generation of multicomponent GCLs is helping make GCL installations even more effective, safer and longer lasting. Advantages in utilising this polymer coating include the topics 5.1 to 5.6 but are not limited to those.

5.1 Prevention of Root Penetration

As plant and tree roots search for water, they spread in all directions horizontally and vertically, and will continue this search until they find enough water to sustain the plant. This search can impact a GCL installation. As described earlier, bentonite hydrates once in contact with fresh water, including moisture from the surrounding soil. Due to the bentonite's outstanding sorption capacity, the bentonite will typically have higher moisture content than the surrounding soil. Roots can be attracted to this moisture. Though high-quality powdered sodium bentonite possesses self-sealing properties, root penetration should not be encouraged. Roots can extract water content from bentonite. Placing the coated slit-film woven geotextile side against the direction of potential root growth will protect the hydrated bentonite core from root penetration - thus, maintaining a high bentonite moisture content and a high level of design safety and sealing performance.

5.2 Increasing Resistance against Desiccation

According to soil mechanics, swellable and hydrated soils shrink when desiccating. In clays, this is typically revealed with cracking. The same mechanics can affect swellable bentonites. Such desiccation can occur in arid and semi-arid areas, in regions with low soil coverage or little rainfall, and in applications where the bentonite does not have constant access to fresh water. Even though needlepunched, fibre-reinforced GCLs will show a much smaller crack pattern than unreinforced or poorly reinforced GCLs, a desiccation crack pattern will increase fluid or gas permeation rates prior to the self-sealing of the bentonite (which occurs upon contact with fresh water). If this is not acceptable for the designed application, the polymer-coated GCL can be used with the polymer coating facing the direction of expected desiccation. In most cases, this will be the upper side of the GCL. The upside-facing polymer coating of the GCL would prevent moisture escape and allow the bentonite to be hydrated and act as a barrier, even in arid areas or under very low confining stresses, such as in tank farm applications.

5.3 Bentonite Piping Resistance under High Water Gradients

When placed over coarse grain soils or other open structures (such as geonets), a question remains as to whether bentonite extrusion or piping can occur under high hydraulic water conditions. Common applications of this nature include canals, ponds, and lagoons. Though needlepunched GCLs with scrim-reinforced nonwovens will provide under laboratory conditions the best performance against bentonite erosion (ROWE et al. 2003), the highest safety against this on-site condition involves the attachment of a polymer coating against the slit-film woven side of the GCL. Bentonite erosion with the coated side facing against the porous subgrade is now virtually impossible, even under high and extreme hydraulic conditions. The long-term sealing performance of the polymer coated GCL is ensured.

5.4 Lower Permeability

Needlepunched GCLs have a strong history as a stand-alone barrier, largely due to the high grade of powered sodium bentonite used in the GCL's construction. This sodium bentonite exhibits high swelling behavior, low water permeability, excellent water absorption and retention capacity, and a unique self-sealing/-healing effect. These exceptional capabilities of the bentonite remain, even with the use of a polymer coating on GCL. This extra coating simply adds its advantages to the GCL which increases the GCL performance. The coating improves overall performance while further lowering the hydraulic conductivity of the GCL. With these advantages now combined, needlepunched GCLs outperform nearly any sealing system in regard to hydraulic conductivity during the service life of the coating and beyond.

5.5 Barrier against Ion Exchange

When a GCL is in contact with fluids and soils containing leachable cations, such as calcium (Ca), magnesium (Mg), potassium (K) or other polyvalent cations, an ion exchange of the sodium (Na) portion of the GCL can occur. If it does, the clay structure of the GCL core can be affected, which might impact the swelling capacity and the hydraulic conductivity performance. However, it is impossible to make general statements on the long-term performance of a GCL under these conditions. Using calcium bentonite instead as the sealing core in a GCL, even with a higher mass per unit area (e.g. 8 to 10kg), is not a suitable option. Published results (Henken-Mellies, 2010; Mueller-Kirchenbauer, 2010) have shown that the hydraulic conductivity results of field exposed calcium bentonite are far higher (fig. 4) than ion exchanged sodium bentonite GCLs (fig. 5).

In applications where this issue might be a concern, a polymer coating on the GCL facing the possible polyvalent cation source can help guard against this possible ion exchange. In most applications water, which is the hydration source for the bentonite, comes from the top and permeates through the soil layer above the GCL. In applications with soils that have a high concentration of free available leachable cations, a coated GCL is an ideal solution. The thin coating facing the source of exchangeable cations acts as a barrier and protects the sodium bentonite sealing core of the GCL.

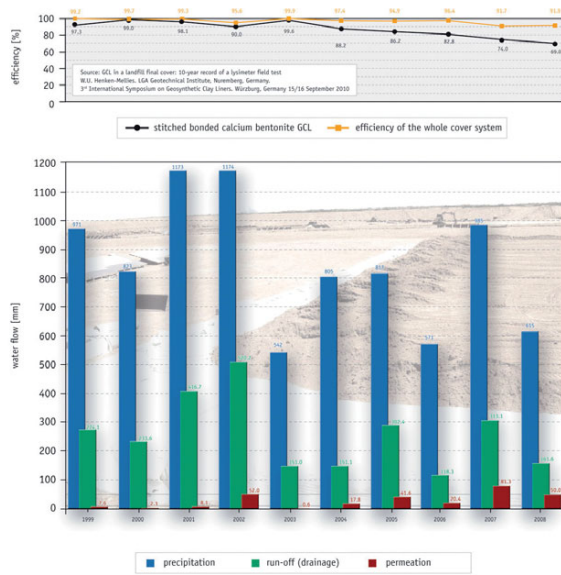


Figure 4: Increasing permeation of a Ca bentonite GCL in a long-term field exposed test plot

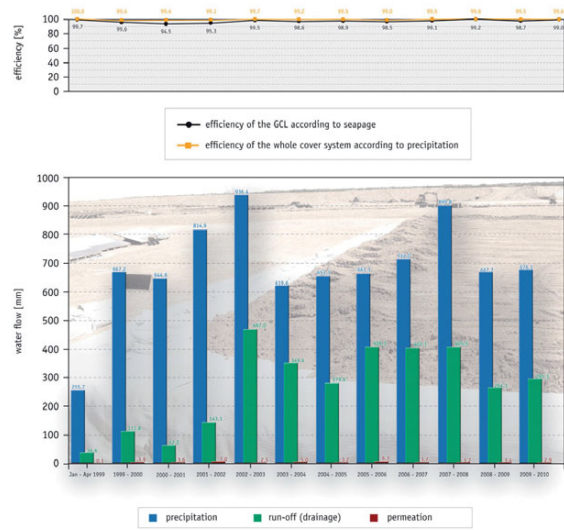


Figure 5: Well performing sodium bentonite GCL in a long-term test plot

5.6 Gas Barrier

In applications in which the GCL has to perform immediately as a gas barrier, the porous bentonite core might not have time to fully hydrate with water and fulfill its sealing performance due to immediate gas migration. Applications of this nature include the waterproofing of underground structures, landfill caps, and other applications in which the GCL is installed over an active source of gas production. The coated barrier of needlepunched GCL would act as the gas-impermeable barrier, thus allowing the installation and welding of a geomembrane.

In applications where no additional barrier is installed in combination with the GCL, such as with underground waterproofing systems, the polymer coating will take over the immediate sealing performance against possible penetrating gas. In both cases the sealing of the coated overlaps of the GCL can easily be carried out with a special bituminous tape.

6. Design Considerations

With its multiple variables, GCLs offer economical, long-term barrier solutions that are ideal for a wide range of sealing applications. Each variety is designed to meet specific barrier situations, such as managing hydraulic heads, reducing the risks associated with chemical environments, guarding against root penetration, and accounting for desiccation. A worldwide supplying major German geosynthetic and GCL manufacturer developed a design Bentogram (NAUE, 2011) which is a new, easy-to-use tool to help identify the right type of GCL for nearly any application. After identifying on a scale of 1 to 10 (10 being the most severe or important) the project's concerns with four key areas that can impact barrier systems: root growth, desiccation, hydraulic head, and chemical influence, the Bentogram allows one to select the proper lining system: a regular needlepunched GCL, a polymer coated needlepunched GCL or a HDPE geomembrane. The corresponding components chart is then used to help identify the suggested best solution for the selected project.

7. Designing with Polymer Coated GCLs

For designing with polymer coated GCLs, additional design issues may need to be considered. These can include but are not limited to one or more of the following topics 7.1 – 7.7.

7.1 Durability of the Coating

In most cases the GCL coating is expected to have a long service life. For this reason, the polymer coating should be manufactured with a highly chemically resistant polyethylene resin.

7.2 Resistance against Installation Stress

It is important to know the resistance of the additional barrier against installation stresses.

7.3 Overlapping of Polymer Coated GCLs

Geosynthetic clay liners are overlapped during installation. To provide security against permeation, additional powdered bentonite is sometimes applied to the overlap zones on site. On site treatment, however, is not as dependable (in that it is not as uniform) as providing the additional bentonite at the edges during the manufacturing stage, e.g. some GCL panels are impregnated during manufacturing on both longitudinal edges with 500mm of additional bentonite. This impregnation ensures that these overlapped, bentonite-treated areas act immediately as a seal without any need for on-site bentonite treatment. In applications where GCLs need to act immediately as a gas or chemical liquid barrier, or in applications where bentonite piping in the overlap zone may be of concern, a special tape (made with a strong adhesive bitumen) is recommended to seal the overlap on the coating side.

7.4 Transmissivity between Coating and GCL

Due to the unique manufacturing process, the polymer coating is added in a fluid state directly on top of the woven component of the GCL. This allows the polymer coating to penetrate into the woven structure, surround the needlepunched fibres from the nonwoven outer geotextile and attach firmly, uniformly and directionally-independent to the entire woven GCL component. In the unlikely event of damage to the coated barrier, penetrating water that could flow under the coated woven component would cause the sodium bentonite layer to immediately swell and form a seal against the damage. This self-sealing characteristic of the GCL prevents a large radial displacement of penetrating water; and it's a characteristic unique to GCLs in barrier system designs.

7.5 Interface Shear

For slope designs, the critical friction plane needs to be investigated with the site materials and is typically confirmed with multiple shear box tests. This is true of nearly all materials considered in slope applications, such as soil, GCLs, other geosynthetics used on slopes, etc. For steeper slopes, the use of geogrid soil reinforcement can significantly improve the slope friction angle.

7.6 Peel Value of Coating

Because GCLs are composite materials and the single layers are designed to work together, the peel bond strength between the GCL components is of particular interest. The needlepunched construction of a specific GCL increases the internal shear strength, ensuring a firm lock between the single GCL outer layers and the powdered sodium bentonite core (Ehrenberg and von Maubeuge, 2008). The same bond holds true when adding the polymer coating as an additional barrier. Even though the interface friction value of the coated material to surfacing materials might be the dominating value, it is important that all possible surfaces and layers are properly investigated to avoid shearing of any type. Special shear testing between the component carrier woven layer and attached polyolefin coating demonstrates a very good peel bond strength, which indicates that this connection face is, under most conditions, not the critical friction surface.

8. Case Study Canada - Mining Job

The construction of a composite cover soil system (figure 6), which includes a needlepunched, thermal locked, polymer coated geosynthetic clay liner (GCL), started with an initial GCL deployment of 10,000m² on day 1 of the project. The local Canadian GCL partner of a worldwide supplying major German geosynthetic and GCL manufacturer along with the general contractor, Hazco Environmental & Decommissioning Services, then completed to deploy 120,000m² in the same year prior to closing the project down for the winter. Construction resumed in the following Spring to complete this 800,000m² soil cover system for the Ontario Ministry of Northern Development and Mines at the abandoned Kam Kotia Mine Site located in northeastern Ontario, Canada. The soil cover would effectively impede the entry of water and oxygen into the high sulphide tailings, substantially reducing acid generation and metal leaching effects from within the tailings.



Figure 6: Landfill cap sealed with needlepunched and coated GCL

9. Summary

The decisions that a designer makes about the GCL itself during material selection heavily influence the ultimate performance and durability of the GCL system. These include decisions on the type of bentonite and its mass per unit area, the overlap design, the geotextile protection elements, confining stress prior to hydration, damage resistance, interface shear strength, durability, overlap sealing, the potential need for a polyolefin coating, and much more. Safety, of course, is of the utmost importance.

Geosynthetic Clay Liners (GCLs) are often used as a stand alone liner or in combination with a geomembrane. They replace thick compacted clay liners due to many advantages, such as easy installation, low hydraulic conductivity, self-healing capabilities, capable of withstanding differential settlement, shear performance and cost effectiveness.

However, the designer should consider site specific conditions (soil material, slope angle, interface friction) and specify relevant characteristics to ensure a long-term and safe design. Current standard GCL properties could be on the lower limit, so that increasing some GCL properties (on the geotextile, bentonite and GCL) are in some cases recommended. The Geosynthetic Research Institute, Folsom has published a White paper (GSI 2005) and a GRI-GCL3 (GSI 2005b) standard and has made aware the necessity to consider several important topics, especially overlap separation under certain conditions of pre-hydrated GCLs. However, this topic can be solved by means of immediate soil coverage or an increasing overlap for these types of products.

The latest GCL development are multicomponent GCLs. One method is adding a polymer coating to the needlepunched GCL which improves the GCL performance and opens more applications where GCLs can be used in. However the additional component is not to replace a high quality geomembrane with this typical thinner barrier.

- Advantages of the polymer coated barriers are:
- Prevention of Root Penetration
- Increasing Resistance against Desiccation
- Bentonite Piping Resistance under High Water Gradients
- Lower Permeability
- Barrier against Ion Exchange
- Gas Barrier

To ensure the longterm performance of polymer coated GCLs other design issues might be of concern and should be considered prior to the installation of the needlepunched GCL:

- Durability of the Coating
- Resistance against Installation Stress
- Overlapping of Polymer Coated GCLs
- Transmissivity between Coating and GCL
- Interface and internal Shear
- Peel Value of Coating

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