Multi-component geosynthetic clay liner improves barrier applications

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ABSTRACT: Geosynthetics have been used in civil and environmental applications for many decades. Primarily functions include separation, filtration, drainage, reinforcement, protection and sealing.
Beyond the basic awareness of the available products, the marked increased use of geosynthetics as a whole appears to have been driven by the many advantages geosynthetics have over traditional construction methods and materials. Advantages include the direct material cost savings, airspace savings for landfills, the reduction of excavation volumes, faster installation rates, improved performance as well as the possibility of steeper slope applications. However, with the technical advances, greater care must be used to ensure the correct product is selected and just as importantly, that the product is properly installed. Poor selection or installation can have the effect of negating the economic and technical benefits.
This paper will touch mainly used geosynthetic systems but focus mainly on geosynthetic clay liners (GCLs) and the recent development of multicomponent GCLs.
Geosynthetic clay liners (GCLs) are mostly needle-punched, fibre-reinforced composites that combine two durable outer layers and an intermediate uniform core of high swelling powder sodium bentonite clay, which acts as the barrier component. These uniform needle-punched GCLs form a direction 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.
GCL improvements, since the invention of needle-punched GCLs in 1987 and contribution to the understand-ing and adoption of GCLs in engineering and construction, have been numerous. This paper will discuss the new GCL technology, the advantages of the polymer coating added to the GCL, the current test results, the applications where such GCL products are ideally used and the necessary design considerations.

Keywords: multi-component GCL clay barrier sealing

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 needle-punching. 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.

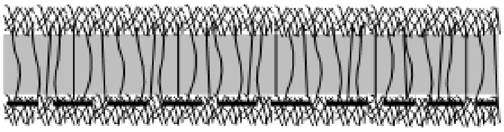

Figure 1. Needlepunched GCL cross-section

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.

2 TYPICAL ADVANTAGES OF NEEDLEPUNCHED 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 se-curity 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 lay-er, 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 con-tributed greatly to the overall field’s understanding of GCL performance. Needle-punching 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 to-wards 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 com-ponent 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 flu-id and allowed to solidify

4 APPLICATIONS FOR POLYMER COATED MULTICOMPNENT GCLS

In general, polymer coated, needlepunched GCLs can be used in all applications (table 1) where long-term sealing barriers, better performance or additional benefits are requested. The polymer coated GCL is most ef-fective, though, when at least one of the described advantages listed in section 5 and 6 is an important design criterion.

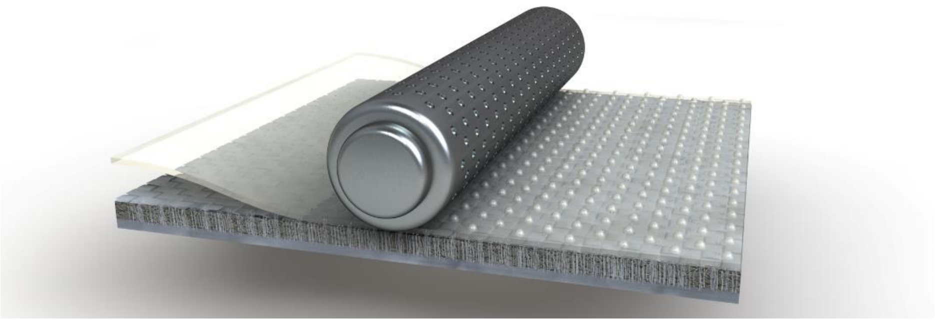

Figure 2. Structured polymer coating added to needle-punched GCL during the manufacturing process

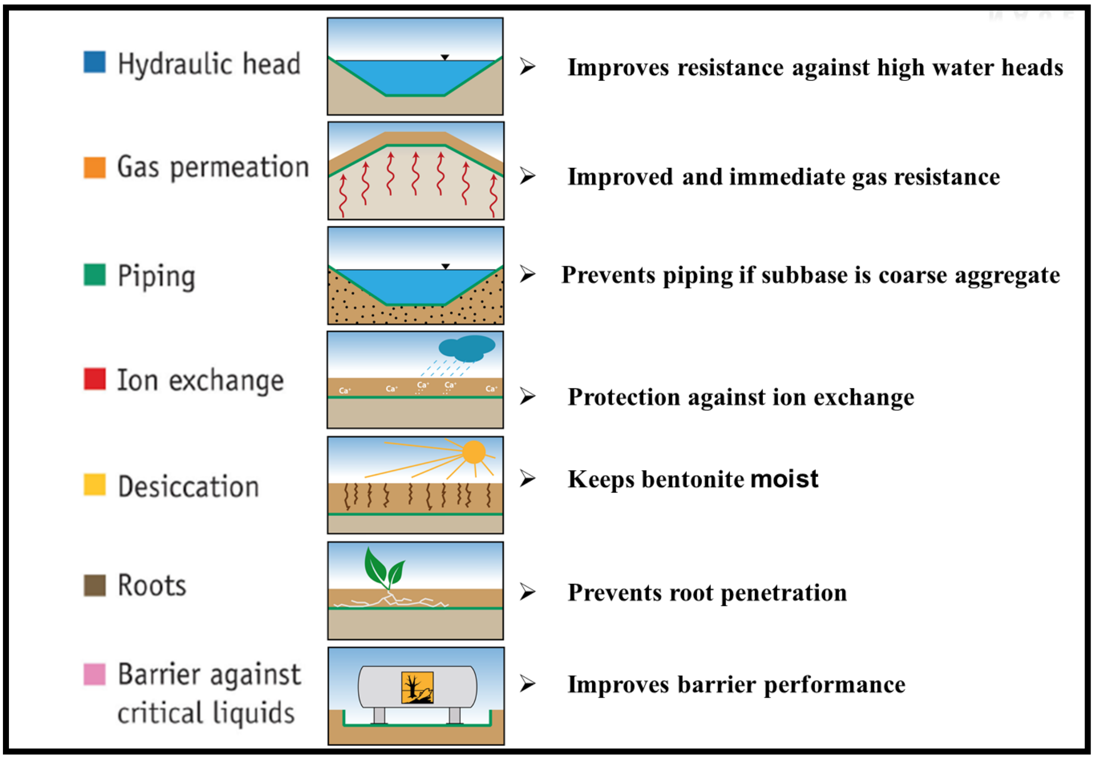

Figure 3. Add-on values, where multicomponent GCLs give a benefit in applicable applications

5 ADVANTAGES OF 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 than ion exchanged sodium bentonite GCLs. 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.

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.

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 6.1 – 6.6.

6.1 *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.

6.2 *Resistance against installation stress*

It is important to know the resistance of the additional barrier against installation stresses. GCLs are not identical, and same is true for multi-component GCLs. A particular GCL can be used in a specific condition, e.g. with sand on the multi-component but could show an issue with gravel material. While sand during the placement will not damage the coating or the laminate, a fine gravel is more likely to damage a stiffer laminate membrane but might not cause any harm to a more flexible coated PE material. Therefore it is important to also consider the installation materials and the installation process, when selecting a multi-component GCL.

6.3 *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 needs 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.

6.4 *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.

6.5 *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.

6.6 *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.

7 CASE STUDIES

7.1 *Beneficial reuse: from landfill to a country park*

The seaside town of Grimsby is located in the northeast of England, situated on the south side of the Humber Estuary. Grimsby is famous for its fishing heritage and remains today an important fish and food processing centre. The town also boasts a thriving chemical and gas power industry. In 2013, the North East Lincolnshire Planning Committee approved the application by landowner Millennium Park to decontaminate a 23.7-hectare former landfill site and convert it into an exemplary, beneficial reuse project: a country park. The development, located in the centrally located West Marsh area of Grimsby, promised 23 hectares of parks, wild life zones, fountains, children's play areas, and open spaces.

Due to the end use being a recreational area, it was important to make sure the capping system was robust, flexible, self-sealing and a proven gas barrier and low permeability barrier to infiltration of water. Also, the beneficial reuse of the site and the enhanced protections that came with that approval meant that multiple types of GCLs were specified. Each type was selected according to the specific zone's design and functional needs.

For 6.5 hectares of the site, Bentofix® BFG 5000 was installed to secure the land on which the main recreation facilities would be constructed. All Bentofix® products contain high-swelling, high-quality powdered sodium bentonite and are manufactured with needlepunch and Thermal Lock (enhanced shear strength) technologies; but Bentofix® BFG 5000 was specified for the recreational facility area for its complete impregnation of bentonite in the nonwoven geotextile, its self-sealing overlaps to ensure a continuous barrier, and its independent BBA Certification for waterproofing and methane/radon barrier performance under confining pressure.

For 16.5 hectares, a coated GCL was used as the low permeability capping system. The coated GCL, which has a special polymeric coating installed facing up, was specifically chosen for this application due its heightened performance against desiccation (which enable a hydrated, restoration soil depth of 450 mm), its protection against ion exchange, its root barrier performance, and its higher gas barrier characteristics.

An additional benefit of the polymeric coating is that it is extruded onto the GCL, so there is no risk of the critical polymer layer delaminating. Some other GCL products use glues instead to fix the laminate to the GCL. However, as typically PE is used as laminate and it is known that one cannot achieve a long-term bond with glue to PE, there would be a mid-term risk of decreasing the interface shear value. This was an important advantage for coated GCLs for the Grimsby site.

Selecting different types of GCLs for specific roles within a design, rather than simply selecting a single barrier, may seem costly because each product is used in a lower volume; but, it isn't really. Specifying based on unique needs at particular project zones ultimately makes for a more precise, cost-efficient project up front and in the long term, as each material performs exactly to the barrier needs where it has been installed. This takes place of other measures that may be needed to make a less-specific barrier system work where it is not ideal.

All materials were independently tested by a third-party laboratory in accordance with the requirements of the government regulator in England, the Environment Agency.

Figure 4. Coated GCL being installed on the Grimsby landfill final capping system

7.2 *GCL-sealed detention basins enable town to continue growing*

Horley, which is located near the border of Surrey and West Sussex in the United Kingdom, has drawn continual development interest due to its convenient connections to major metropolitan areas and transportation options. It also has its own thriving economy and local amenities. The town is five minutes from Gatwick Airport and 45 minutes from the south coast resorts. With fast, round-the-clock railway links to London, it remains a big draw for commuters.

To support the next phase of Horley's development, a proposal for a major new development known as West Vale was accepted. The site would support 1,500+ homes, a new primary school, and a neighbourhood centre with shops, pubs/restaurants, and other community facilities.

A consortium of four main partners – Crest Nicholson, A2Dominion, Taylor Wimpey and Persimmon –secured over £40 million for infrastructure and service improvements on the 99 hectare development.

Phase I of the project included roughly 600 residential properties, but the irregular crescent-shape land area of the overall development, which was an undulating, former arable field in near proximity to the River Mole, presented flood planning concerns. Final approval for Phase I was contingent upon the development team being able to demonstrate a satisfactory control of potential flood waters.

The Borough Council requested drainage works that could store and gradually release flood water at the same rate as water had discharged in the area prior to development. WSP Parsons Brinckerhoff, serving as the consulting engineering firm, proposed a system of four detention basins to provide attenuation with water quality treatment and a flow control device in each basin to manage discharge into the river.

A geosynthetic clay liner system was specified to provide the essential seal in each basin. The ponds, which were excavated to an average depth of around 6 m, were proposed with 20 – 25% inclines. NAUE carried out the slope stability analysis to ensure the lining system was compatible with the site's engineering needs. Factoring in the underlying geology (Alluvium, River Gravels, and London Clay) and the planned usage of cement stabilised fill materials.

This type of coated GCL is characterized by a uniform layer of natural sodium bentonite powder encapsulated between two strong and durable polypropylene geotextile layers – one layer woven and the other nonwoven. Importantly, a polyethylene coating is bonded to the woven layer.

For Horley, it meant that prior to hydration an immediate low permeability barrier would be created and counteract any incompatibility between the sodium bentonite and the cementitious backfill.

The 4.85m-wide GCL rolls were delivered to site and installed quickly and efficiently with 30cm overlaps by Breheny Civil Engineering, the project's contractor. Though the GCL solution was significantly thinner than a conventional compacted clay layer would be—6 mm thickness for the GCL versus 500 mm thickness for a comparable compacted clay layer—the GCL provided equivalent or greater sealing performance. The unique fibre-bonding process with the needle-punched nonwoven fibres of Bentofix® also provided high internal shear strength and creep resistance that secured the GCL on the slope in ways that a compacted clay system could not match.

Furthermore, each truckload of GCL included 4,000m² of material; whereas, a truckload of a traditional clay lining would cover just 25m². In these ways, the GCL saved considerable time and money for the construction works, as well as providing a better carbon footprint for the development.

Roughly 30,000m2 of coated GCL was installed during West Vale's Phase I activities.

Figure 5. Coated GCL being installed as the essential seal in each water storage basin

8 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 prehydrated 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, etc.

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.

REFERENCES

EHRENBERG H., von MAUBEUGE K. P., 2008, "Long-term Shear Strength Testing with Geosynthetic Clay Liners and Geosynthetic Drainage Mats", The First Pan American Geosynthetics Conference & Exhibition, Cancun, Mexico

Geosynthetic Research Institute, 2005, GRI-GCL3 Standard Specification for Test Methods, Required Properties, and Testing Frequencies of Geosynthetic Clay Liners (GCLs), Folsom, Philadelphia

Geosynthetic Research Institute, 2005b, GRI White Paper #5, http://www.geosynthetic-institute.org/papers/paper5.pdf Folsom, Philadelphia

HENKEN-MELLIES W.-U., 2010; "GCL in a landfill final cover: 10-year record of a lysimeter field test", 3rd International Symposium on Geosynthetic Clay Liners Würzburg, Germany

von MAUBEUGE K.-P; LENZE B.,2007, "Landfill Cap design with Geosynthetic Clay Liners", 2nd Portuguese Seminar on Geosynthetics,

MUELLER-KIRCHENBAUER A., BLUEMEL W., von MAUBEUGE K. P., 2010; "Performance of Geosynthetic clay liners in landfill cap sealing systems - physical processes in the bentonite layer during drying and rehydration periods", 3rd International Symposium on Geosynthetic Clay Liners Würzburg, Germany

ROWE R. K., ORSINI C.;2003, " Effect of GCL and subgrade type on internal erosion in GCLs under high gradients", Geotextiles and Geomembranes 21