Alcoa World Alumina

APPLICATION GUIDE GEOSYNTHETIC CLAY LINERS (GCLs) FOR RESIDUE DISPOSAL AREAS

AWASTD323 Application Guide – Geosynthetic Clay Liners (GCLs) for Residue Disposal Areas (AWA)

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1.0 Introduction

1.1 General

Alcoa owns and operates bauxite residue storage areas (RSAs) across its nine global alumina refineries. The impoundment / containment system in each RSA consists of a low permeability liner system which forms a hydraulic barrier in preventing the contamination of groundwater from highly alkaline bauxite residue leachate (BRL).

Alcoa Residue Disposal Area (RDA) design, construction, and operation shall comply with Alcoa's mandatory standard "60.4 – Bauxite Residue Management Standard", in addition to compliance with the local government's regulations.

1.2 Emerging Technology

As new methods and technologies become available, Alcoa investigates and ensures that these can be applied and adapted in its operations at a risk level that is equivalent to or better than current best practice. Design innovations, in consideration of site-specific conditions, which meet or exceed Alcoa's and regulatory standards, whilst at the same time reduce capital and operating costs are encouraged and supported.

Over the past two decades, geosynthetic-based liner systems have been becoming widely accepted by industry and regulators in waste containment / landfill applications. As Alcoa's RSA operating locations find it increasingly difficult to source sufficient quantity of good quality clay for RSA construction, the Engineering Technology Group (ETG) began an investigation into alternative liner materials in 2004.

This document has been prepared to provide guidance for Project Managers and Civil Designers who would be considering the application of Geosynthetic Clay Liners (GCLs) for construction of bauxite residue impoundments and containment facilities. The current level of research findings in Alcoa permits the use of GCLs only in a very conservative manner – **GCLs should only be used in conjunction with an impervious geomembrane such as a hdpe liner, and only as a supplementary containment layer to the traditional clay/geomembrane composite liners, <u>not</u> as a clay layer replacement.**

The highly alkaline nature of Alcoa's BRL presents unique challenges which are significantly different to the typically acidic mine and waste landfill situations.

2.0 Current Criteria

2.1 Design

In addition to complying with the local statutory regulations for RSAs, the current liner standard stipulated in the mandatory Alcoa Bauxite Residue Management Standard ESD document 60.4 (Ref 1) is:

> "A constructed low permeability base and embankment seal that is at least equivalent to a 0.5m depth of mechanically compacted clay with a permeability coefficient of less than 10^{-9} m/sec"

RSA projects across AWA typically adopt a composite liner system consisting of a 0.5m thick compacted clay liner (CCL) meeting the 1 x 10^{-9} m/sec impermeability criteria; overlain with a 0.8 mm thick pvc or 1.5mm thick hdpe geomembrane (GM).

2.2 Current State of the Art

The diminishing supply of good quality clay and associated increase in transportation costs for construction of new RSAs requires the need to seek alternative impermeable liner systems for sealing of these facilities. There are many options available, however past research has indicated that the use of a GCL system in a composite combination provides the most cost effective solution.

There is currently no data on the long term (eg beyond 5 years) field integrity of GCLs in a high alkalinity (pH 12 and above) environment. This aspect remains an area of ongoing study. Previous Alcoa studies on clay cores extracted from 20 year old, clay lined RSAs indicated that clay had good impermeability in the early years, however after several years in contact with BRL, chemical changes in the clay structure resulted in increases in its permeability (G Thomas et al.). This observation led to the use of pvc and hdpe geomembranes (GMs) as an additional protective layer over the compacted clay layer.

Laboratory tests to date, particularly with sodium based bentonite GCLs in the US, Melbourne and Western Australia, have indicated no negative short term performance with respect to hydraulic permeability in regard to the GCL bentonite reacting with high pH Alcoa bauxite residue leachate. The impact due to long term chemical reactivity is an area still requiring further understanding.

Sodium based bentonite has proven to be superior to calcium based, hence the choice of suitable GCL supplier(s), their bentonite source and consistency in quality and material standard are of critical importance.

3.0 GCL Application Process

3.1 GCL as Supplemntary Layer

Although widely used for many years in major waste/landfill projects throughout the world, GCLs have not been used in bauxite RSAs, hence there is no knowledge outside of Alcoa on the short and long term performance of GCLs in such facilities.

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Current level of Alcoa experience permits the use of GCLs in RSA construction strictly in a conservative manner. As a rule, the traditional GM-CCL system comprises of a pvc or hdpe geomembrane, laid over a 0.5m compacted clay layer. The clay must meet the Alcoa impermeability criteria (1 x 10^{-9} m/sec or less) and is usually sourced locally or from a borrow pit in the vicinity of the project site. On projects where it is too difficult or uneconomical to source sufficient clay quantity and/or quality, GCLs may be considered. **The GCL shall be included in a composite geomembrane-GCL-clay (GM-GCL-CCL) combination, <u>as a supplementary layer</u> to the lower quality clay layer (ie <u>not</u> as a total replacement for a clay layer).**

3.2 GCL Prequalifications

Due to the variability of natural clays and GCL products (eg different bentonite/chemical composition from different sources, powdered vs granular form, pre-hydrated vs non hydrated GCL, bentonite encapsulation, etc), the proposed GM-GCL-CCL composite layer shall be carefully assessed, custom-designed and verified through short term laboratory testing by the Design Engineer on a project / case specific basis, unless prior evaluation and test results are available. This is to ensure BRL-GCL chemical compatibility, the Alcoa impermeability criteria of 1 x 10^{-9} m/sec or less, and the requirements as described in the Alcoa GCL (draft) standard AWASTD323 are being met. **Sufficient lead time (eg at least 3 to 6 months) should be allowed for assessments and laboratory testing (if required) to be completed for the proposed GM-GCL-CCL system.** For the project, the selected GCL supplier(s) will need to verify product consistency and clay borrow must be also be verified for consistency.

3.2 Prior Review and Approval before Field Application

Prior review and approval of the proposed GM-GCL-CCL system design is required from the Alcoa Residue Lead Team, via the Residue Civil Technical Team, before application in the field.

This above application process will be reviewed annually in light of more research and industry data progressively becoming available.

4.0 GCL Design

The liner system described below is not intended to be an approved standard and should be viewed as a guide to illustrate the appropriate application of a GCL in a composite GM-GCL-CCL system, requiring further detailed geotechnical and hydrogeological assessments to be undertaken.

4.1 The Liner System in Detail

The final configuration of a GM-GCL-CCL liner system will vary from project to project, depending on the availability and quality of clay on site, the field insitu conditions, choice of GCL, as well as the case specific geotechnical and hydrogeological parameters used in any analytical modelling.

The Design Engineer shall refer to the following Alcoa Standard Specifications as the basis for the project-specific geosynthetic liner specification:

a) AWASTD300 RDA Design Standard

b) <u>AWASTD320 PVC Geomembrane Specification</u>

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c) AWASTD321 HDPE Geomembrane Specification

d) AWASTD322 LLDPE Geomembrane Specification

e) AWASTD323 Geosynthetic Clay Liner Specification

available by contacting the RLT or RCTT.

Low permeability soil liner shall be equivalent to at least a 0.5m-thick layer of mechanically compacted clay with a permeability coefficient not greater than 1 x 10^{-9} m/sec.

As an alternative to the standard requirement of 0.5m thick, mechanically compacted clay with a minimum permeability coefficient of 1 x 10^{-9} m/sec, subject to proven equivalencies of chemical compatibility and low permeability, an alternative GM-GCL-CCL liner system may comprise of the following:

a) A geomembrane (GM) - hdpe, pvc or lldpe.

b) A GCL - prehydrated, manufactured from *natural sodium bentonite* encapsulated between upper and lower non-woven polypropylene geotextiles, preferably in powdered form, with a mass per unit area of not less than 5 kg/m^2 (see AWASTD323 for GCL product specification and testing requirements).

   The chosen GCL shall be chemically compatible with the site environment as proven by a site-specific GCL/BRL (Bauxite Residue Liquor) testing program per ASTM D6146 - "Standard Guide for Screening Clay Portion of Geosynthetic Clay Liner (GCL) for Chemical Compatibility to Liquids" and ASTM D6766 - "Standard Test Method for Evaluation of Hydraulic Properties of Geosynthetic Clay Liners Permeated with Potentially Incompatible Liquids"

c) A layer of CCL or bentonite-amended soil - a minimum 0.4m thick of permeability coefficient not more than 1 x 10^{-7} m/sec. The top 150mm shall not have particles greater than 5mm.

The designer shall provide for approval, a GM/CCL – GM/GCL/CCL (or amended soil) Equivalency Analysis for the proposed liner system to establish equivalency between the conventional CCL and the alternative GCL design. The analysis shall cover the following technical issues:

a) Hydraulic issues i.e., hydraulic barrier capacity (steady flux of water) and leakage rate

b) Physical and mechanical issues i.e., slope stability, puncture resistance, freeze-thaw, and wet-dry

c) Construction and operation considerations i.e., constructability, weather constraints, supply and construction quality assurance / construction quality control systems (QA/QC). Check supplier's source of quarry supply and how bentonite grade and quality consistency is maintained.

d) Method of prehydrating the GCL, including verifying quality of water used. Note - (hardwater rich in Ca is not recommended)

The designer shall demonstrate that the chosen geosynthetics for the liner system are mechanically and chemically compatible with the RSA applications

Appendix A

GCL General Technical Data

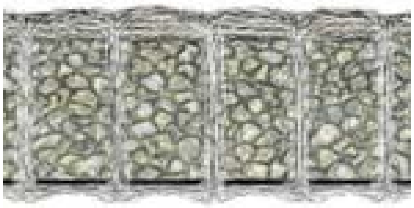
APPENDIX A

GCL General Technical Data

(courtesy of Y Zhou, Geotechnical Specialist, Alcoa Global Primary Products Group - Growth, Energy, Bauxite & Africa)

GCL Introduction

Developed in late 1980s, GCLs represent a relatively new technology currently gaining acceptance as a hydraulic barrier in waste containment applications.



As shown above, a GCL is a relatively thin layer of processed bentonite clay either bonded to a geomembrane or "needle punched" between two sheets of geotextile. Although the overall configuration of the GCL affects its performance, the primary performance factors are clay quality, amount of clay used per unit area, and uniformity.

Bentonite is an extremely water-absorbing and swelling clay formed from volcanic ash. Bentonite attracts positively charged water particles. It rapidly hydrates when exposed to liquid, such as water or leachate, providing a permeability of 10^{-11} m/sec. As the clay hydrates it swells, giving it the ability to "self-heal" holes in the GCL. In laboratory tests on bentonite, researchers demonstrated that a hole up to 75mm in diameter will seal itself, allowing the GCL to retain the properties that make it an effective barrier system.

GCL technology offers some unique advantages over conventional CCL. GCLs, for example, are fast and easy to install. GCL is cost-effective in regions where clay is not readily available, and provides a superior GM/GCL/Clay composite liner where natural clay is available. As GCLs are as thin as 6mm thick, it saves precious air space.

GCL Performance

Performance issues such as leakage rate, puncture potential, chemical attacks, chemical attenuation, QA/QC procedures, and confining pressure need to be addressed in site-specific GCL applications.

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Puncture Potential

GCL is thin compared to CCL. Thus it is more susceptible to puncture damage. The key issue for the possible puncture damage is the existence and size of sharp objects such as rock fragments in the prepared liner sub base.

In order to minimize the possible puncture potential, the top 150mm of the sub base underlying the GCL shall not have particles greater than 5mm. These size-controlled materials will protect the GCL from being punctured. In addition, a stringent QA/QC plan in sub base and superstratum preparations and GCL placement needs to be implemented to reduce and eliminate the puncture potential.

Chemical Attacks by pH and Salinity

Certain constituents of landfill leachate may attack bentonite of the GCL and compromise its hydraulic sealing performance. pH and salinity are two reported parameters that may adversely impact the GCL performance.

Therefore, to adequately address the GCL performances under a site condition, the designer needs to perform a comprehensive site-specific testing program involving characterization of the site leachate and hydraulic conductivity of the proposed GCL using the leachate as influent. The following tests are generally performed:

- Leachate pH (both field and laboratory)
- Leachate Salinity
- Leachate Volatile Organic Compounds (VOCs)
- GCL Bentonite Free Swell Using Leachate as Hydration Liquid
- GCL Hydraulic Conductivity Using Leachate as Influent

High pH is a primary concern for using GCL in contact with bauxite residue. Jo et al (Ref 6) reported that "pH only influenced swelling and hydraulic conductivity when the pH was very low (<3) or very high (>12)." While some limited studies have been conducted in recent years by Alcoa using high pH (>12) bauxite residue leachate, site-specific testing is recommended on a project by project basis.

Salinity is reported to adversely affect GCL performance. Leachate salinity impacts on GCL hydraulic conductivity should be tested.

Salinity is the concentration of salt in water. Concentration is the amount by weight of salt in water and can be expressed in parts per million (ppm), or salinity unit (s.u.) that is 1,000 ppm. The salinity classes of water are:

- Fresh water - less than 1,000 ppm, (< 1 s.u.)
- Slightly saline water - From 1,000 ppm to 3,000 ppm, (1 to 3 s.u.)
- Moderately saline water - From 3,000 ppm to 10,000 ppm (3 to 10 s.u.)
- Highly saline water - From 10,000 ppm to 35,000 ppm (10 to 35 s.u.)

Ocean water has a salinity that is approximately 35,000 ppm (35 s.u.). That's the same as saying ocean water is about 3.5% salt. Currently, salinity of neutralized bauxite leachate is not available for preliminary evaluation. Site-specific testing is recommended.

Chemical Attenuation

As the utilization of GCL in waste containment system becomes widespread, lessons learned from the applications and ensuing researches on the GCL performance have revealed and confirmed that traditional performance equivalency analysis based on water transmission and leakage is not enough. In fact, diffusion of VOCs can be a significant mechanism of contaminate transport in the composite liner system including GCL.

Chemical attenuation of a soil layer is needed for neutralizing diffusion of VOCs. Generally, because the bauxite leachate characterization does not contain VOCs, diffusion of VOCs is unlikely to occur at the site. Although additional soil layer for chemical attenuation is not required if VOCs are not present, it is

QA/QC Procedures

The project QA/QC plan and the GCL Specifications will provide detailed quality control requirements and implementation procedures. Highlights of such requirements and procedures include:

- Refining of raw material – The key component bentonite of the GCL will be strictly defined as a distinct type of fine-grained clay soil typically containing not less than 80% montmorillionite clay, characterized by high swelling upon wetting. A set of manufacturer quality assurance tests will be required and verification tests will be performed upon GCL delivery to site to ensure compliance of the GCL to project specifications.
- GCL storage, handling and shipping – Specific requirements for GCL storage, handling and shipping will be provided in the QA/QC plan and the GCL Specifications. Basically, these requirements will be implemented to ensure that integrity of the GCL is not compromised during storage, handling, and shipping.
- Intimate contact – Intimate contact between the GCL and the overlying geomembrane will be promoted by implementing QA/QC procedures to eliminate winkles, fish-mouth, and any other out-of-plane irregularities of the GCL and geomembrane sheetings.
- Secondary conduits – Any secondary conduits in situ will be detected and closed off in accordance with the QA/QC plan and the GCL Specifications.
- GCL subgrade – To prevent puncture, the sub base for GCL will be a layer of size- controlled material. Before placement of this material, the subgrade accepting the material will be visually inspected for and subsequent removal of ponded liquid and other large size objects. Therefore, any intrusive chemicals that could damage or pre-hydrate the GCL should be removed.

GCL Confining Pressure

The GCL placement should be installed strictly in accordance with the manufacturer’s recommendations (refer also to ASTM D6102). Only GCL that can be covered during the same workday by a geomembrane should be deployed. The laying of the geomembrane and superstratum layer above the GCL should proceed without delay to apply the confining pressure on the GCL. Generally, the GCL needs to be subjected to a minimum confining pressure of approximately 2 psi (13.8kPA) upon completion of the liner system but before the waste placement. This confining pressure is adequate in keeping the GCL in place without significant expansion upon possible exposure to moisture. After the waiting period, the confining pressure will increase as the waste placement progresses, further restricting and lowering the hydraulic conductivity of the GCL.

Regulatory Acceptance of GCL

Australian and United States federal and state regulations specify design standards for bottom liners and final covers. Alternative liner systems are allowed through equivalency demonstration that they meet federal performance standards. GCL technology is an alternative that performs at or above standard federal performance levels (Ref 3).

Some government agencies accept GCL as a replacement of CCL, without equivalency demonstration. For example, Nebraska State Department of Environment Quality states (Ref 4) that

“The Department believes that in terms of steady flux of water, the GCL is probably equivalent to two feet (0.6m) of compacted clay liner (CCL) at 1x 10^{-7} cm/sec permeability. Therefore, an alternate liner design demonstration is not required when a GCL is substituted for the permeability requirement of the CCL component of a composite liner design.”

Appendix B

References

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VERSION UPDATE INFORMATION			
Version No.	Issue Date	Change Details	Change By
A	1/11/2009	Issued for Approval	D Foo –ETG / RCTT