Optimising terminal asset integrity and safety through the use of emerging materials, technologies and innovation

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ABSTRACT: Geosynthetic Cementitious Composite Mats (GCCM's) were originally developed in 2005 and are a relatively new material technology in the world of geosynthetics. GCCM's consist of a flexible 3-dimensional fibre matrix filled with a high-early strength dry concrete mix with a PVC membrane laminated onto one side. In this way they combine geotextile, geomembrane and concrete technology enabling geosynthetics to be used in completely new markets and applications.
Geosynthetic Cementitious Composite Barriers (GCCB's) were developed as an extension of the GCCM technology and largely driven in response to the more demanding rules and regulations imposed on petrochemical terminal operators over recent years. This paper is an overview of this innovative material technology, including details of key properties and how these can be fully utilised in application. It will demonstrate through case history, how GCCB's have found their place in a crowded market and brought strong, tangible benefits to the various stakeholders tasked with managing petrochemical facilities on a day-to-day basis.

Keywords: Geosynthetic Cementitious Composite Barrier, GCCB, Geosynthetic Cementitious Composite Mat, GCCM, Geosynthetic Barriers, Impermeability, Secondary Containment

1 INTRODUCTION

With an increasing awareness and greater focus placed on environmental protection and the impact that petrochemical assets have on their surroundings, operators are continually challenged with the use of traditional materials to ensure compliance and safe working when implementing large scale construction projects.

The last decade has seen a real shift in the regulation of the Oil & Gas industry, since the major conflagration events, such as Buncefield, UK and Longford, Aus. The vast majority of Countries are now either reviewing, or already implementing new legislation, aimed at not only new projects, but those that have been operating for many years. For example, the PGS 29 regulations, which apply to cylindrical storage tanks operated in the Netherlands, now set out far more stringent regulations than previously adopted regarding containment structures, inspection and ongoing maintenance. Hence, with Amsterdam and Rotterdam having a very high concentration of terminals and assets, this one piece of legislation alone has extremely dramatic and far reaching effects for everyone involved in these critical operations.

For this paper, we will focus on one of the key applications commonly employed in terminal operations, secondary containment systems, specifically trapezoidal bund or berm walls. These features are one of the most common forms of environmental protection utilized in the industry and it is still surprising to some, that they should largely consist of earth profiles which are allowed to naturally vegetate.

Therefore, when we consider how these systems could be brought in line with current legislation, there are many aspects that need to be considered:

- Increased impermeability
- Erosion control
- Vegetation suppression

- Animal attack
- Reduced contractor burden
- Certifiable and testable installation

Geosynthetic Cementitious Composite Barriers, GCCB's were specifically developed with these requirements in mind and will be covered in more detail, as follows:

1.1 GCCB is defined as "A factory assembled geosynthetic composite consisting of a GCCM (Geosynthetic Cementitious Composite Mat) and a polymeric geomembrane to be used for the containment of liquids."

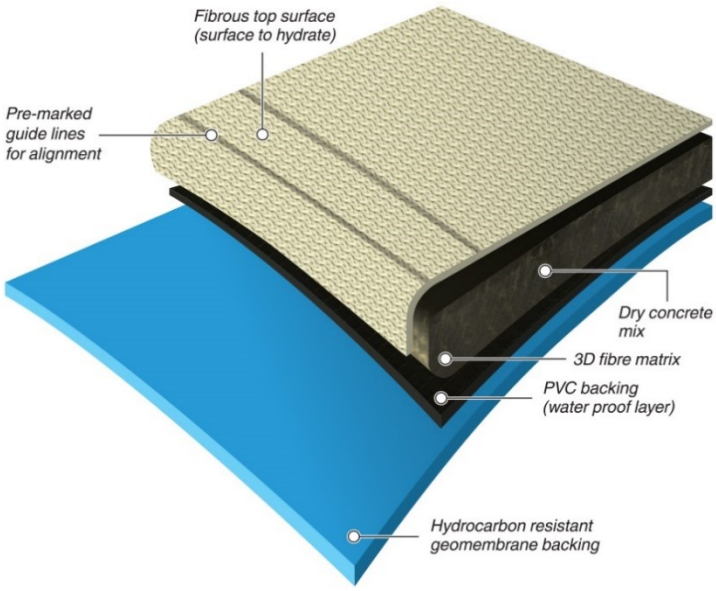

Figure1. Typical section of GCCB

The material construction consists of 4 layers:

- A fibrous top surface layer (typically polyester)
- A 3-dimensional fibre reinforcing matrix filled with a specially formulated dry, high early strength cementitious blend
- A low permeability polymeric bottom layer (typically PVC)
- A low permeability and chemical resistance geomembrane

The top 3 layers are essentially a GCCM which will form a layer of hard concrete once hydrated with water and set. The geomembrane layer will perform as a barrier to contain liquids in the event of a primary containment failure.

With the unique combination of hard concrete cover and impermeable geomembrane layer, GCCB offers a long-term, maintenance-free, durable and efficient bund lining material solution.

2 KEY PROPERTIES

2.1 *Chemical resistance*

An important requirement to consider when selecting a bund lining material for secondary containment is chemical resistance. Observational testing was conducted on a wide variety of applicable samples of membranes immersed for 28 days in various reagents at room temperature to compare their performance.

Samples were visually and physically examined upon removal, and rated according to retention of their working properties after 24 hours and 28 days of exposure. GCCB's have exhibited good chemical resistance at both 24 hours and 28 days periods, against a wide range of industrial liquid products.

Table 1. Chemical resistance of various material (source: Concrete Canvas Internal test)

24 hour/ 28 days	GCCB	Polypropylene	HDPE	PVC	Bitumenous Membrane
Acid*	A/A	A/A	A/A	A/A	A/A
Diesel	B/B	B/X	A/A	B/X	X/X
Digestate	A/A	A/A	A/A	A/A	A/A
Ethanol	A/A	A/A	A/A	A/A	A/B
FAME (Biodiesel)	A/B	B/X	B/B	X/X	X/X
Leachate	A/A	A/A	A/A	A/A	A/A
Paraffin (kerosene)	A/B	B/X	B/X	B/X	X/X
Petrol (Gasoline)	A/B	X/X	B/B	X/X	X/X
Sewage**	A/A	A/A	A/A	A/A	A/A

Rating key:
A-Fluid has little or no effect, B-Fluid has minor or moderate effect, X-Fluid has severe effect. * 0.1MHSO pH1.2 ** synthetic according to OECD 303.

2.2 *Impermeability*

One of key designed properties of a GCCB is an extremely low coefficient of permeability, which is often referred to as the "k" value as derived under Darcy's Law. Good compacted clay will have a "k" value of $1x10^{-9}$ m/s. This has generally been the reference standard for most lining requirements in the past. However, with emerging technologies and innovation, new lining materials have presented values for coefficient of permeability as low as $1x10^{-12}$ m/s, as illustrated in the table below:

Table 2. Type of lining materials and its coefficient of permeability.

Lining Material	Coefficient of permeability, K (m/s)
Compacted Clay	$1x10^{-9}$
Geosynthetic Clay Liner	$1x10^{-11}$
HDPE Geomembrane	$1x10^{-12}$
GCCB	$1x10^{-12}$

The coefficient of permeability can be determined using a triaxial cell under the test method as defined by BS 1377: Part 6. The test method involves fitting a cured disc of the material sample into a tri-axial cell, which is then sealed in place with silicone sealant. The cell is filled with the fluid of concern (water, diesel or others), with the flow set perpendicular to the specimen. The specimen disk is allowed to saturate for 1-2 days before the fluid is pressurised. During the pressurised stage of the test the hydraulic gradient of the fluid is monitored and from this the coefficient of permeability is calculated.

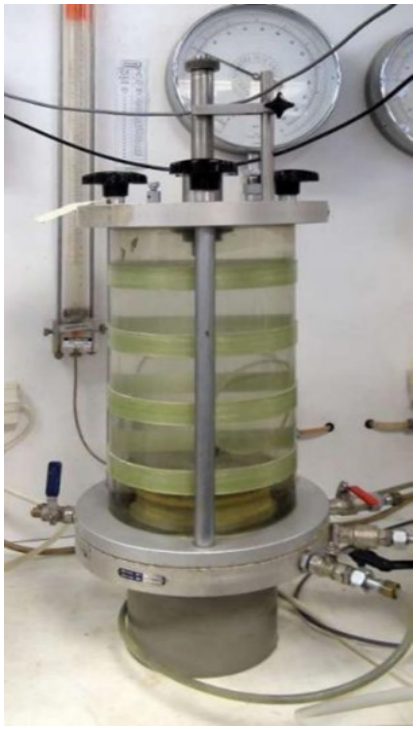

Figure 2. Triaxial Cell

When considering rolled, geomembrane products, such as GCCB's or HDPE's, the maximum available width delivered is often below the actual project width, hence field connections are common. The coefficient of permeability on a connected joint of HDPE or GCCB geomembrane material can be determined using a similar test method as described.

2.3 *Durability*

Long term durability of a lining material is essential when considering that to remain "fit-for-purpose" it must withstand the rigors of daily trafficking and various climatic conditions. The key factors that cause most lining materials to degrade are weathering and UV radiation. Hence, it is common to install a protective top-cover material, such as sand, aggregate, or concrete to cover the liner, providing protection against UV or impact damage.

As the top surface of a GCCB is a thin, uniform concrete layer, there is no further requirement to satisfy the need of protection to the lining material. This provides both long term durability and weather resistance to the system, which is tested under BS-EN 12467: 2004. The GCCB material passes all these advanced ageing tests with little or no negative effect to the physical performance.

Table 3. Test result on weathering

Test Description	Requirement	Result
Freeze-Thaw: 1-2 hrs at (-20 ± 4) °C freezing & 1-2 hrs immersed in water (-20 ± 4) °C	100 cycles	Pass
Soak-Dry: 6 hrs at (60 ± 5) °C drying & 18 hrs immersed in water >5°C	50 cycles	Pass
Heat-Rain: 2 hrs 50 mins ± 5 min water spray & 2 hrs 50 mins ± 5 min radiant heat	50 cycles	Pass

2.4 *Puncture resistance*

The puncture resistance of a lining material is important, especially during installation when risk of damage is highest. It is almost counter-productive to consider that when installing a protective top cover solution to an HDPE membrane, for example, it is this process that is most likely to damage the material it is there to protect. Certainly, removing the requirement for a post installation top-cover layer is a very positive advantage of GCCB's.

There are various test methods to determine puncture resistance. The variance of these methods is primarily on the rod size and tip profile shape. GCCB products have been tested for their puncture resistance according to ASTM F1306 - Standard Method for Penetration of Flexible Barriers.

ASTM F1306 test method is critical compared with ASTM D4833 and EN ISO 12236 due to its sharp rod as can be seen in the following illustration:

Figure 3. Rod size and shape of different test methods.

Table 4. Typical puncture resistance value of 5mm & 8mm thick GCCB.

	GCCB (5mm thick) Mean value	GCCB (8mm thick) Mean value
1st Peak Force (N)	413	987
Penetration (1st Peak) (mm)	3.44	2.23

3 APPLICATION

As described in more detail in the introduction, there is an increasing awareness on environmental protection on terminal sites and secondary containment requirements have become more stringent than ever before. The bund lining materials have evolved from simple bitumen-based products to high performance materials such as GCL / geomembranes.

GCCB is the latest high-performance material that specifically addresses this market application and provides many user benefits over more traditional and established technologies.

The applications of GCCB are not only limited to bund lining in the petrochemical industry. It has recently been expanded to other areas such as:

- Tertiary lagoon lining
- Weed suppression under pipe tracks
- Tank floor sealing
- Concrete remediation

It is commonly considered that with such an innovative material, such as GCCB, the current described applications have only just scratched the surface in terms of the enabling uses this technology could bring to the industry.

4 COMPARISON AGAINST TRADITIONAL SOLUTIONS

The conventional method of lining an earthen bund is to apply 50mm thick of bitumen conglomerate surfacing as shown in figure 4 below. This has often been set in the guidelines of many of the terminal operators around the world.

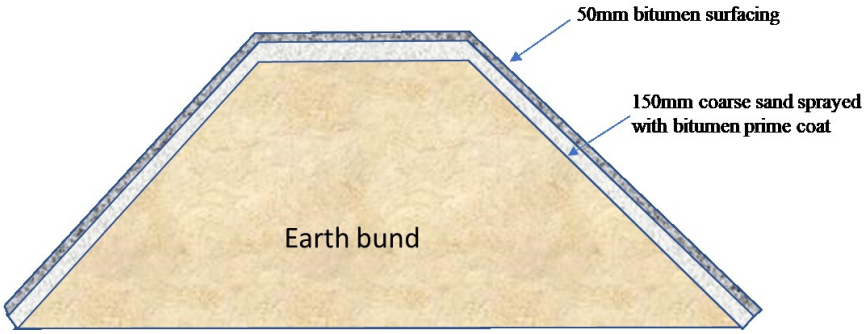

Figure 4. Typical earth Bund

There are some issues with this bitumen-based lining technology. Firstly, the installation is time consuming as it is difficult to spray bitumen on the graded slope. Secondly, the maintenance of the bitumen surface over a period of time can be costly and time consuming to perform. Whilst the bitumen-based lining can be cost effective in comparison, it usually has problems of UV degradation, oxidation, softening under high temperature and lack of resistance against other hydrocarbons such as fuels and oils.

Another material that has gained recent popularity are clay liners with low hydraulic conductivity of 1x10-9m/s with top-cover of suitable soil of 200-300mm thick. This solution provides better advantages over the bitumen-based lining solution in terms of durability, however, it requires a thick soil cover to keep the clay constrained when wet. It is quiet common to have a finishing layer specified to protect this soil cover from erosion and loss of height, hence a traditional concrete layer can still be added as a final hard armour capping layer.

A GCCB with its rigid concrete surface and high impermeability, chemical resistance geomembrane, is much more durable than bitumen-based lining as it sees no problems with UV degradation and chemical attack. The expected life span of GCCB is estimated to be in excess of 50 years under UK conditions and climate. It is with some certainty that we can deduce that GCCB's can reduce the long-term maintenance cost of a lined secondary containment bund.

5 INSTALLAITON

The installation of GCCB has many similarities with other geomembranes, such as HDPE, as they can be thermally welded to provide a uniform sealing system. The basic steps of installation for GCCB are as follow:

- Prepare substrate so that it is firm and free of rocks, vegetation and sharp objects
- Roll out the GCCB and rig into place over the berm profile
- Secure GCCB with proper anchors at the crest and toe of the slope
- Thermally weld GCCB panels with qualified installation engineers
- Hydrate the GCCB with an excess of water

The quality of the thermal welding process will govern the final impermeability of the GCCB system, hence it is extremely important to select qualified installation engineers to carry out thermal welding on GCCB.

One particularly good welding method that has been developed for GCCB installation is called Triple Track Welding and can be seen in detail as shown in figure 5 below.

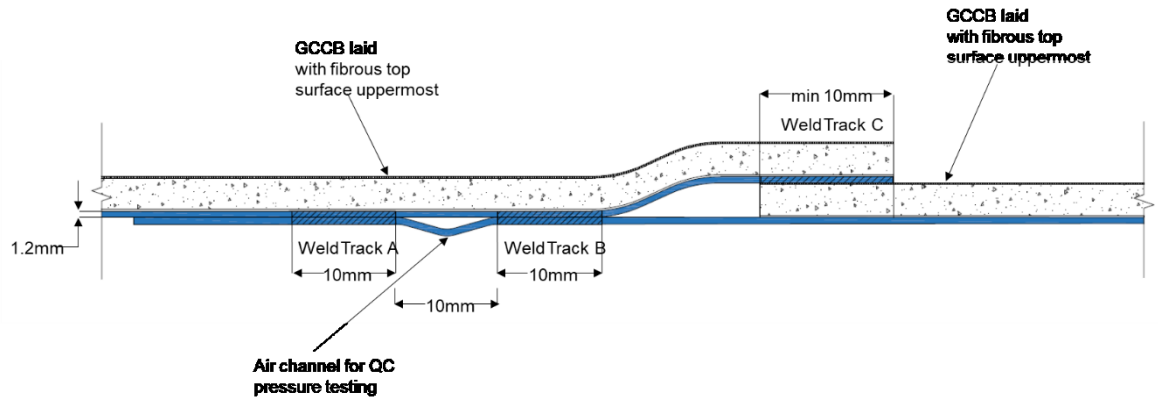

Figure 5. Triple Track Welding of GCCB

This method has been developed in order to have a reliable Construction Quality Assurance (CQA) test carried out without damaging the GCCB material when installed. In essence, a comprehensive non-destructive quality assurance test on the complete installation.

An air channel is created between weld track A and weld track B for pressure testing as shown in figure 6. This non-destructive testing is to verify the strength and impermeability of a thermally welded joint in accordance to ASTM D-7177. The purpose of Weld Track C is to prevent a possible ingress of wind uplifting the GCCB panels.

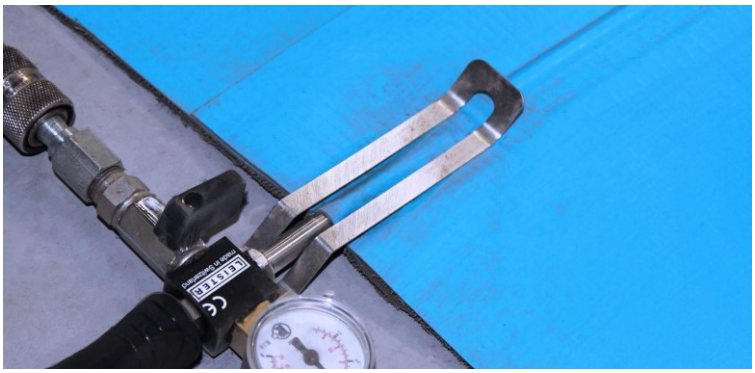

Figure 6. Air pressure testing

6 CASE STUDY

One storage operator that has used GCCB's as lining material for secondary containment is Sem Logistics, Milford Haven who are one of the largest petroleum products storage facilities in the UK, accounting for nearly 25 percent of the UK's independent multiproduct storage. Located on the Milford Haven waterway on the west coast of Wales, the facility serves ships transporting in and out of international locations.

Figure 7. Milford Haven oil storage facility in UK

There are 52 tanks of various sizes within the site that are used to store different petrochemical products: gasoline, gasoline blendstocks, naphtha, jet fuel, gas oil and diesel, as well as crude oil. Each tank sits within a bunded area formed with granular fill during the original construction of the site.

As part of ongoing improvements, SEM embarked on a programme to install secondary containment around two of the site's most critical storage tanks. SemLogistics engaged Mott MacDonald to design a robust solution which takes into account safety during construction, use and maintenance and ease and speed of installation.

After completing cost comparison analysis considering several design scenarios, GCCB was chosen as part of major investment into providing secondary containment for tank 114. GCCB, as well as satisfying the required regulatory and environmental requirements, offered an opportunity to significantly reduce the construction time, operational disruption and cost of secondary containment works within the site.

GCCB is effectively an all-in-one solution, combining the low permeability of a containment liner with the hard armour protection and durability of concrete, reducing install times and simplifying logistics. GCCB does not require a protective top cover. This removed the need for additional excavation, the treatment of contaminated arisings and the import of costly fill material. It was possible to maintain the original volume capacity of the bund asset, as the GCCB was laid directly onto existing profiles providing significant overall time and cost savings.

As mentioned in paragraph 2.2, GCCB has excellent impermeability and has been independently tested to BS-EN-1377 to have a hydraulic conductivity better than $1x10^{-12}$ m/s. This gives a factor of safety over and beyond alternative solutions with standard impermeabilities of $1x10^{-9}$ m/s.

In addition to meeting the impermeability required, GCCB provided effective weed suppression eliminating the ongoing maintenance cost of soil covered systems. Incredibly durable, GCCB has a hard armour surface, protecting the geomembrane liner from puncture, abrasion, weathering, burrowing animals and UV degradation. This all contributed to the reduced life-cycle costs of the material compared to other options.

Figure 8. GCCB is easy to install on pipe penetrations.

Figure 9. Installed GCCB

A total of 4000m2 of GCCB were installed in under 5 months despite very adverse weather conditions. For a facility like SemLogistics getting the tank back in service on time was of paramount importance in order to meet their client's expectations.

7 CONCLUSION

We have shown in this paper how GCCB's can be installed as an extremely successful solution for secondary containment bund lining projects when compared to other more traditional material technologies available on the market.

We believe GCCB's have a bright future in not only the oil and gas market sector, but various other areas that are as yet unknown to us. With such an innovative product, the scope of application is limitless and over time, GCCB's will continue to facilitate important projects and be an ever increasing part of the world we live in.

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