Geosynthetic Composite Cementitious Mats (GCCMs) - State of the art in 2016

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ABSTRACT: Geosynthetic composite cementitious mats (GCCM's) are a relatively new entrant into the geosynthetic market. The development of GCCM's, which is a combination of geotextile, geomembrane and concrete technology pushes the boundary of applications for geosynthetics into new markets which have been traditionally served by concrete products.
Since being developed in 2005, GCCM's have continually been advanced in performance, quality and scope of application.
This paper is an overview of GCCM technology and what the current status of the technology is. It will give an overview of
- what a GCCM is
- their competitive advantages
- testing that has been conducted, geosynthetic and cementitious tests
- successful applications have been developed so far - canal and ditch lining, slope protection, bund lining
- development of new applications - secondary containment
- ongoing development of standards for GCCM's for use in geosynthetic applications.

Keywords: cementitious, erosion, GCCM, concrete, armor

1 INTRODUCTION

Geosynthetic composite cementitious mats (GCCM's) are a relatively new entrant into the geosynthetic market.
Much in the same way that back in 1988 GCL's integrated two distinct fields of material science, i.e. geosynthetic textiles and mineral clay technology, which have now been developed and are a staple product in containment applications worldwide. So too GCCM's combine, geotextiles, geomembranes and high strength cement technology to push the boundary of applications for geosynthetics into new markets. Markets which up until now were beyond the performance capability of geosynthetic products and have been traditionally treated using alternatives to geosynthetics i.e hard armour solutions such as stone, rock or concrete products.
Since being developed in 2005, GCCM's continue to advance in performance, quality and scope of application.

2 EXPLAINING GEOSYNTHETIC COMPOSITE CEMENTITIOUS MATS – GCCMS

2.1 *What is a GCCM?*

A GCCM (Geosynthetic Cementitious Composite Mat) is a flexible, cementitious impregnated fabric that hardens on hydration to form a thin, durable, low permeability and fire resistant cementitious lining (Concrete Canvas 2015).
This composite product consists of a

- knitted polyester hydrophilic top surface
- 3-dimensional fibre reinforcing matrix
- filled with a specially formulated dry high early strength cementitious blend and
- PVC coating on the bottom surface to provide a very low permeability

Figure 1. Cross section of 8mm GCCM showing various component

2.2 *Hydration of GCCM*

Once installed and anchored, the GCCM can be hydrated either by spraying or by full immersion in water. Non–potable and saline water are suitable for successful hydration of GCCMs. As a general rule, water requirements for hydration are 500ml of water per kg of GCCM but this varies considerably depending on atmospheric conditions. A more detailed hydration plan should be considered on a per project basis, based on specific project circumstances and manufacturers recommendations (Concrete Canvas 2015 - Hydration).
After setting, the fibres reinforce the concrete, preventing crack propagation and providing a safe plastic failure mode.

Figure 2. Application of water onto an installed GCCM – begins the curing process

2.3 *Beneficial geocomposite properties of GCCMs*

A geocomposite is the amalgamation of various geosynthetic products to provide a multi-component product, having the beneficial characteristics of its component products.
GCCM is a composite of polyester carrier fabric, polyester reinforcement, cementitious filler and a PVC backing coating. The GCCM therefore derives beneficial engineering properties from all of these carefully selected and combined components in a single layer.

- The polyester carrier fabric provides containment for the cementitious filler – which provides consistency in thickness and a hydrophilic surface to draw moisture during the hydration process
- The polyester reinforcement provides a dense reinforcement matrix - which provides tensile strength crack resistance
- The cementitious filler provides compressive strength, durability and excellent resistance to UV and weathering, abrasion, a broad range of chemicals and PH ranges.
- The PVC coating on the underside provides low permeability

2.4 *Competitive advantages of GCCMs vs conventional concrete – Lower logistical footprint*

Depending upon the application, a GCCM can replace a non-structural shotcrete layer with a single composite layer. The thickness of the GCCM which may only be from 3% to 10% of the required thickness of the proposed structural concrete.
Example 1. A typical 5mm thick GCCM has successfully replaced 50mm thickness of unreinforced shotcrete. Based on volumes alone, there is a saving of 90% in transport costs by using GCCM over conventional shotcrete.
Example 2. A 10 tonne flatbed truck can deliver 7 rolls of 5mm x 200m2 GCCM to site, 7 x 1400kg = 9,800 kg or 1,400m2. If this 1,400m2 was lined with 50mm thick shotcrete, it would require 70m3 of concrete or about 9 trucks holding 8m3 of concrete each.
There are also many instances where GCCM have been selected instead of shotcrete because access to the workface was just too difficult for proper mobilisation and setup of the shotcrete equipment.

Figure 3. GCCM used for weed suppression, mobilisation of shotcrete equipment was not possible without major shut down of train lines

Figures 4 and 5. Typical packaging of GCCMs, makes them easier and cheaper to transport than conventional concrete.

Table 1. Comparison of tons of material used - GCCM vs conventional concrete*.

GCCM thickness (mm)	Roll width (m)	Mass unset (kg/m2)	Portable roll size			Bulk roll size (m2)			Concrete alternative (2400 kg/m3)	
			Length (m)	Area (m2)	Weight (kg)	Length (m)	Area (m2)	Weight (kg)	Concrete thickness (mm)	Weight of concrete (kg)
5.0	1.0	7.0	10	10	70	200	200	1,400	75	36,000
8.0	1.1	12.0	5	4.5	60	113	125	1,500	100	30,000
13.0	1.1	19.0	-			73	80	1,520	150	28,800

*Adapted from (Concrete Canvas 2015)

2.5 *Competitive advantages of GCCMs vs conventional concrete – consistency of product and properties*

Finishing tolerances of shotcrete are dependent on finishing class (ACI Committee 117 – 1990). For most erosion control applications, class D is specified which allows thickness tolerances of +25mm. This can be very wasteful over large areas. Compare this with GCCM which have tolerances of ±0.5mm.

Table 2. Comparison of thickness tolerances between GCCM's and shotcrete

Description		Shotcrete placement tolerances as a % - by finish Class. Based on 100mm thick shotcrete
Shotcrete - allowable finish types		
Class D	typical finish achievable from gun application	25.4%
Class C	excellent finish achieved from gun application	16.0%
Class B	typical finish, required float and trowelling	9.5%
Class A	excellent finish, require screed, float and trowel	6.4%
GCCM - tolerances		
	5mm ± 0.5mm	10.0%
	8mm ± 0.5mm	6.3%
	13mm ± 0.5mm	3.9%

3 TESTING OF GEOYNTHETIC COMPOSITE CEMENTITIOUS MATS – GCCMS

Another challenge that arises with the development of GCCM products is selection of appropriate testing methods and properties of the material. The properties of the material before hydration and curing are very different from those of the final in service product.

In its hardened, cured state a GCCM does not behave like any existing geosynthetic product, so alternative testing methods – outside of the conventional geosynthetic arena had to be considered. After considering and adopting some concrete testing methods, it was realized that a GCCM can best be considered as a fibre reinforced cementitious sheet, so much of the mechanical properties and weathering of GCCM's have been tested to BS EN 12467:2004 Fibre-cement flat sheets. Product specification and test methods.

Nonetheless, in order for the place of GCCM's to be understood within the area of geosynthetics, some tests which are typically conducted on geosynthetic products have also been conducted and will be dealt with first.

While tensile testing is one of the most telling tests to establish mechanical properties of geotextiles and geomembranes, GCCMs behave more like fibre cement sheets, as it turns out 3 point flexural bending tests are more appropriate to consider changes in strength or flexibility in GCCMs than tensile tests.

3.1 *Cured GCCM – Tensile testing*

The cured samples had to be modified to be tested correctly (Concrete Canvas 2012). Samples were 300mm x 100m with 2 slots cut in the top and bottom ends and steel brackets inserted which held the specimen in place and were in themselves held by the jaws of the tensile machine. Two 25mm horizontal cuts were made in either side of the specimen, in order to reduce the width of the test sample to 50mm. For these tests, the tensile machine was run at 50mm/min.

Table 3. Ultimate tensile strength of various GCCM thicknesses*

Thickness (mm)	Tensile Strength (kN/m)	
	MD	CD
5.0	6.7	3.8
8.0	8.6	6.6
13.0	19.5	12.8

*Adapted from (Concrete Canvas 2015 – General Guide)

Typical tensile curves for GCCM's show 3 phases,

- Initial elastic phase – cracking of the reinforced cementitious material
- Incremental rupture phase – sequential loading and breaking of the reinforcement and
- Final rupture (Milliken 2015)

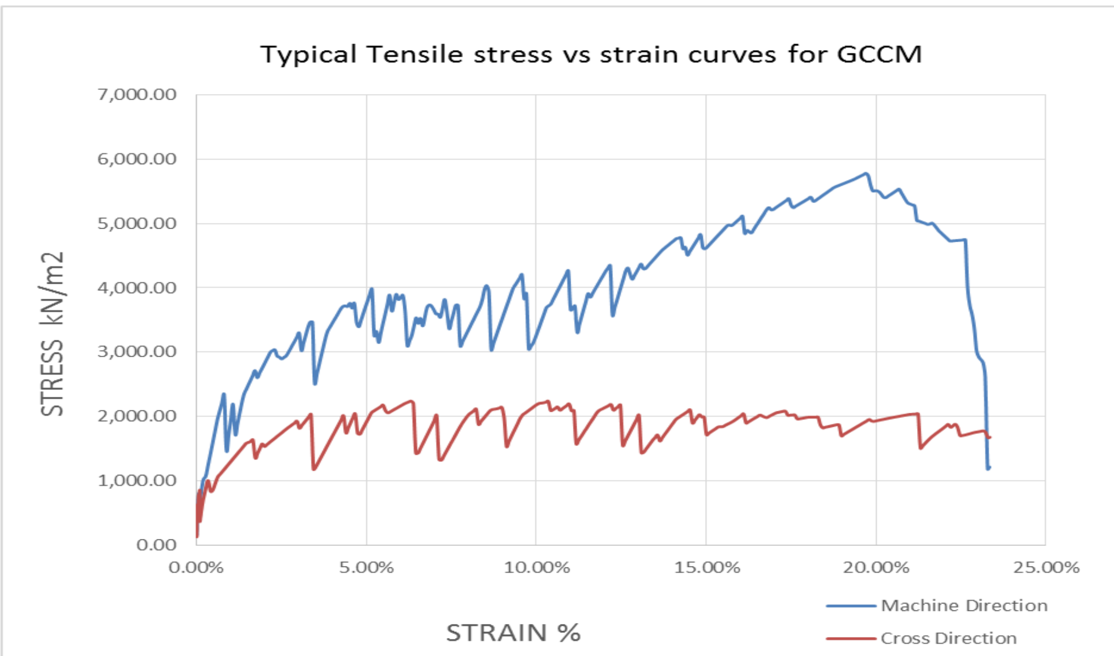


Figure 6. Typical tensile curves for hardened GCCM

3.2 *Cured GCCM – Puncture resistance testing*

Puncture resistance testing was carried out to ASTM D-6241 using a flat 50mm diameter plunger with the material constrained in a 150mm diameter circle. The plunger is moved at 50mm/min speed.

You can see quite clearly the 3 phases here also, elastic, loading and rupture. Once again testing of a material with properties more similar to concrete than textiles meant that the cured samples had to be modified to be tested correctly (Milliken 2015).

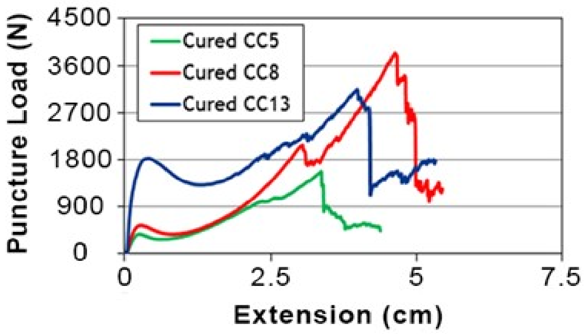


Figure 7. Typical puncture resistance curves for hardened GCCM

3.3 *Cured GCCM – Permeability Testing*

Permeability of GCCM's have been tested to BS 1377 part 5 and all thicknesses achieve permeability of between $k = 1 \times 10^{-8}$m/s and 1×10^{-9}m/s
Permeability was tested using the constant pressure method.

3.4 *Cured GCCM – Hydraulic Testing*

In 2012 and 2013 hydraulic testing was performed in accordance with ASTM D6460 "Test Method for Determination of Rolled Erosion Control Product (RECP) Performance in Protecting Earthen Channels from Storm water Induced Erosion" (Milliken 2013).
The two main objectives from these experiments were to establish a Manning's 'n" value and to determine the maximum permissible flow velocity and shear stress that GCCM could resist as a system. Results were

- Established an average Manning's "n" value of 0.011
- The test apparatus was run at maximum velocity of 10.7m/s which produced 1200 Pa of shear stress and no movement of the GCCM, the seams or erosion underneath was recorded.

3.5 *Cured GCCM – Chemical Resistance Testing*

The three different thicknesses of GCCM were tested to BS EN 14414:2004 "Geosynthetics. Screening test method for determining chemical resistance for landfill applications".
This involved 56 days of full immersion at 50°C into

- Acid (pH 1.0) – sulphuric acid
- Alkali (pH 13.0) – sodium hydroxide
- Hydrocarbons (35% diesel, 35% paraffin and 30% lubricating oil)

Finally, the samples were tested in bending using the 3 point bending test to compare flexural strength properties before and after immersion (Concrete Canvas 2015 – Chemical Resistance).

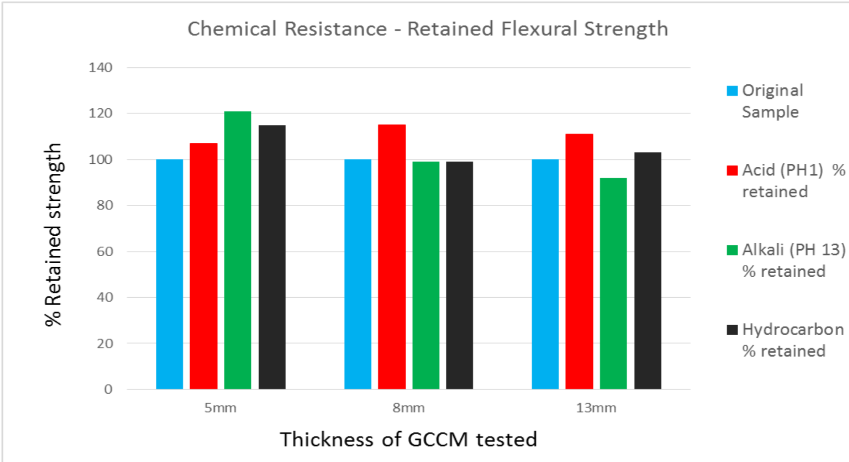


Figure 8. Retained flexural strength of GCCM after chemical immersion

3.6 *Cured GCCM – Root resistance testing*

Tests carried out by BICS Laboratory Ltd (UK) according to DD CEN/TS 14416:2005.

- 5mm GCCM samples were cured and typical overlap joints using the adhesive bead jointing method were produced.
- Lupin seeds grown for a period of approximately 4 months.

No evidence of penetration either through the GCCM or the joint was observed on any of the samples tested (Concrete Canvas 2014).

4 TESTING OF GCCMS - AS FIBRE REINFORCED SHEETS

After curing GCCM's become thin reinforced cementitious sheets. The following tests have been conducted to appropriate concrete and cement standards. Durability testing has been conducted to BS EN standard 12467:2004 Fibre-cement flat sheets. Product specification and test methods for testing of fibre-cement sheets.

4.1 *Curing GCCM – Flexural Bending*

Being relatively thin and brittle, with the main failure mechanism for hardened GCCM's is in flexural bending. The 3 point flexural bending test is used to best understand and analyse the flexural strength properties and degradation of GCCM's.
Bending tests based on BS EN 12467:2004 (initial crack) are used with typical results of 3.4MPa for 10 day bending failure stress.

4.2 *Cured GCCM – Compressive Strength*

Compressive tests on the cementitious binder used in GCCM were performed based on ASTM C109 – 02.
The 10 day compressive failure stress of 40MPa were recorded, to initial crack.

4.3 *Cured GCCM – Durability testing to BS EN 12467:2004*

Durability testing designed to assess the effects of environmental degradation on fibre reinforced cement sheets was conducted on GCCM's of various thicknesses. The testing specifically addressed the durability of reinforced fibre cement sheets in applications where they may be subjected to heat, high moisture and severe frost.

GCCM's passed the Category A Weather Resistance requirements - the highest level of weather resistance for fibre cement sheets. Based on these test results CC can be expected to resist normal weathering for a minimum of a 50-year lifespan for outdoor installations in the UK climate (Concrete Canvas 2015 – Durability).

Table 4. Summary of the durability testing requirements for 50yr exposed service life expectancy

Physical requirements and characteristics	Classification	Requirement	Result
Apparent density: (set CC)	N/A	>1900 kg/m3	Pass
Bending strength	Class 1	4-7MPa	Pass
Water impermeability	Category A	Impermeable	Pass
Warm water: (60 ± 2) °C	Category A	(56 ± 2) days	Pass
Durability requirements			
Soak-dry: 6hrs at (60 ± 5) °C drying & 18hrs immersed in water >5°C	Category A	50 cycles	Pass
Freeze-thaw: 1-2hrs at (-20 ± 4) °C freezing & 1-2hrs immersed in water (20 ± 4) °C	Category A	100 cycles	Pass
Heat-rain (2hrs 50mins ± 5 min water spray & 2hr 50mins ± 5 min radiant heat)	Category A	50 cycles	Pass

4.4 *Cured GCCM – Abrasion resistance*

Abrasion resistance testing based on ASTM C – 1353 has been conducted using the Taber 5150 Abrasion equipment.
The graph of abrasion resistance of GCCM material showed 2 distinct behaviours

- Initial stage – with the PET cover material, rate of abrasion was similar to that of 20MPa OPC concrete
- Second stage – with the PET cover material removed, rate of abrasion was similar to that of 64MPa OPC concrete (Milliken 2014).

4.5 *Initial curing shrinkage*

Currently the allowable shrinkage during the hydration/curing process for GCCM's is below 0.15% (Brewin 2015). To prevent the contraction of the GCCM during this phase, generally 15kg ballast or similar capacity anchors are required during installation at a spacing of less than 2m and at all internal corner details (Concrete Canvas 2015 – Ditch Lining).
These restraints are temporary, after 24hrs the GCCM has cured and achieved 80% of its strength the curing shrinkage phenomenon ceases and restraint is no longer required.

4.6 *Flame resistance*

GCCM's have been tested for resistance to flame and have achieved two notable approvals

- Acceptance of technical specification for use under 30 CFR – Standardized small scale flame test procedure for the acceptance of roof-rib grid material. Testing conducted by MSHA - Mine Safety and Health Administration, Approval and Certification Centre. Concrete Canvas (2012)
- "B-s1, d0" Euroclass Fire rating system, based on EN 13501 Part 1. (Concrete Canvas 2015 – Fire Resistance)

5 JOINTING METHODS

The basic method to joint 2 adjacent panels of GCCM is an overlap seam. The material is overlapped by 100mm and fixed together with 32mm stainless steel screws at 200mm crs. Various alternative methods to construct a seam between two GCCM panels have been investigated and extensively tested, resulting in the following guidelines been issued on the different methods, depending upon project requirements. (Concrete Canvas 2015 – Jointing Guide)

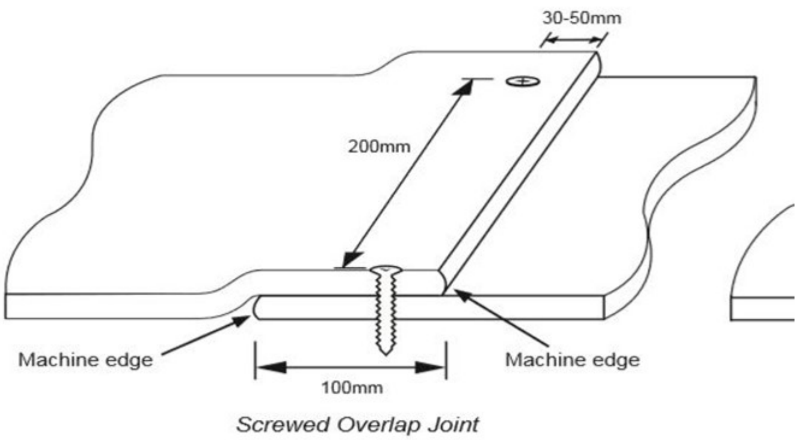


Figure 9. Standard overlap seam details for joining GCCMs

Table 5. Recommended jointing methods for GCCM, depending on project requirements

			INSTALLATION				
	STRENGTH*	**IMPERMEABILITY***	*Speed*	*Skill*	*Tools Required*	*When to use*	**RECOMMENDATION**
Screwed (overlap)	●●●○○ (1400 N/m)	●○○○○	Fast	Low	Autofeed Screwdriver	Most common joint used on 95% of applications	25-30mm stainless steel screws with 200mm spacing installed using autofeed screwdriver
Screwed and Sealed (overlap)	●●●○○ (1700) N/m	●●○○○	Med	Low	Autofeed Screwdriver and Caulking Gun	For applications where a level of impermeability is required	25-30mm stainless steel screws with 200mm spacing. Sealed with Everbuild Clearfix
Adhesive Sealant (overlap)	●●●○○ (1700) N/m	●●●○○	Med	Low	Caulking Gun	Used where screws are not suitable due to a concrete substrate or membrane under CC	Sealed with bead of adhesive sealant such as Everbuild Clearfix
Grout (overlap)	●●●●○ (2000) N/m	●●●●○	Slow	Med	Trowel & Bucket / Concrete Spraying Machine	A higher strength, high impermeability alternative to an adhesive sealant joint	Jointed using CC specific grout with minimum thickness as per Grout Guide
Thermal Weld (prayer)	●●●●● (2900) N/m	●●●●●	Fast	High	Thermal Welder and Power Supply	High strength joint used to create a seal with the same impermeability as the CC itself	Use automatic welder such as Leister Twinny T or S (The Twinny T has data logging capability)

* Joint strength and impermeability data is intended for guidance purposes only. Joint performance may vary depending on the quality of the installation and the application conditions. Strength data is based on the ultimate strength of a tensile peel test in laboratory conditions.

6 SUMMARY OF APPLICABLE STANDARDS

Several technologies have been brought together to develop GCCM's.

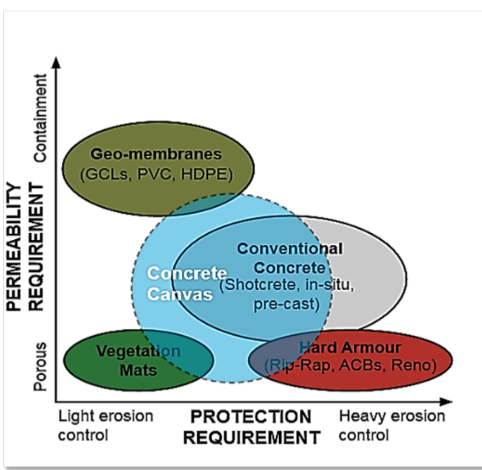
- BS EN 12467:2004
- BS EN 13501-1:2007+A1:2009
- BS EN 14414
- DD CEN/TS 14416:2005
- MSHA ASTP-5011
- ASTM C109 – 02
- ASTM C1185
- ASTM C-1353
- ASTM D6460
- ASTM G13

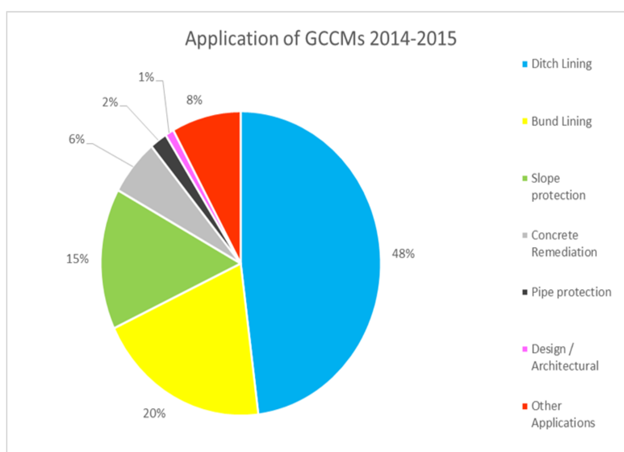
Currently the ASTM D35.05 Committee on Geosynthetics have 3 Work items for GCCM's in development.

- WK49618 – New Test method, sample preparation for GCCM's
- WK49719 – Determining Flexural Strength of GCCM's , 3 point method
- WK50957 – Installation of GCCM's

7 WHERE DO GCCMS FIT INTO THE GEOSYNTHETICS MARKET?

While the properties of GCCM do cross over into a small area of conventional geosynthetic applications, GCCM have low permeability and high protection properties, so they predominantly compete directly against non-structural shotcrete and concrete in ditch lining, bund lining, slope protection and concrete remediation applications. This is best depicted by the 2 graphics below. Concrete Canvas (2015) and Crawford (2015)





Figures 10 and 11. GCCMs fill a gap in the geosynthetic market, replacing non-structural concrete. Graphics courtesy of Concrete Canvas

8 LATEST DEVELOPMENTS IN GCCMS

GCCM technology is continually increasing. The 4 main areas of development are

- Improvement of product performance, quality and consistency
- Development of relevant standards and regulations governing the manufacture, design and installation of GCCMs
- Application of existing GCCM's into new applications and
- Development of new products based on GCCM technology

8.1 *Launch of GCCM-PVC containment and armoring product*

In October 2015, a new variation of the GCCM was launched into the market. It consists of a GCCM laminated to a hydrocarbon resistant PVC geomembrane, designated as GCCM-PVC. This product is aimed at applications which would benefit from having both the armoring and protection layer of a GCCM, with the containment properties of a dual track welded PVC geomembrane. GCCM-PVC has already been successfully used in several petrochemical and anaerobic digester bunds, as a permanent one layer solution (Concrete Canvas 2015 - CCHydro)

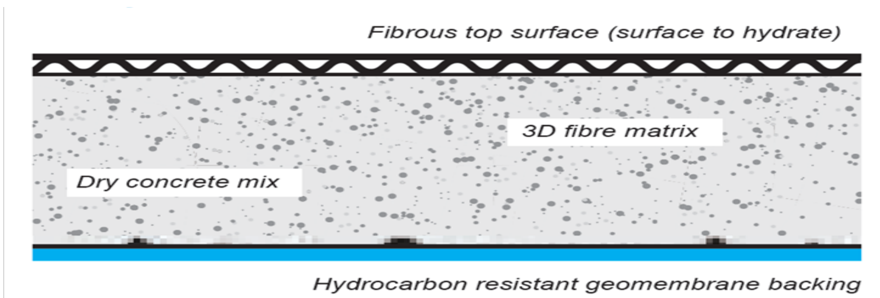


Figure 12. Schematic of a GCCM-PVC, showing the GCCM laminated to a 1.5mm PVC geomembrane

9 REFERENCES

American Concrete Institute, Committee 117- 1990, Standard Specifications for Tolerances for Concrete Construction and Materials, American Concrete Institute (ACI), Detroit).
Brewin, P. (2015) Remediation Guidance and Update, *Concrete Canvas Distributor Meeting October 2015*
Concrete Canvas Ltd (2012) Tensile Testing
Concrete Canvas Ltd (2012) MSHA Fire Certification
Concrete Canvas Ltd (2014) Concrete Canvas – Root Resistance Testing
Concrete Canvas Ltd (2015) Concrete Canvas User Guide – General
Concrete Canvas Ltd (2015) Concrete Canvas User Guide – Hydration
Concrete Canvas Ltd (2015) Chemical Resistance Testing
Concrete Canvas Ltd (2015) Durability Testing 50yr Ageing Certification
Concrete Canvas Ltd (2015) Concrete Canvas User Guide – Ditch Lining
Concrete Canvas Ltd (2015) Concrete Canvas Fire Certification
Concrete Canvas Ltd (2015) Concrete Canvas User Guide – Jointing and Fixing
Concrete Canvas Ltd (2015) Concrete Canvas – Understanding the Market
Concrete Canvas Ltd (2015) CCHydro Technical Literature
Crawford, W. (2015) Introduction Presentation, Concrete Canvas Distributor Meeting October 2015
Milliken Infrastructure Solutions (2013) Hydraulic Testing of Concrete Cloth
Milliken Infrastructure Solutions (2014) Technical Note, Concrete Cloth Abrasion resistance Phase 1
Milliken Infrastructure Solutions (2015) Technical Overview of Concrete Cloth