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Protection of reinforced soil structures using geosynthetic cementitious composite mats

L. Church
Concrete Canvas Ltd, Pontypridd, United Kingdom

C. Doulala-Rigby
Tensar International Ltd, Blackburn, United Kingdom

ABSTRACT: Geosynthetic cementitious composite mats (GCCMs) are a relatively new material technology in the world of geosynthetics. GCCMs consist of a flexible 3-dimensional fibre matrix filled with a high-early strength dry cementitious mix with a polymeric membrane (often PVC) laminated onto one side. They harden on hydration to form a durable, fibre reinforced cementitious layer. In this way they combine geotextile, geomembrane and concrete technology enabling geosynthetics to be used in completely new markets and applications. This paper considers the use of GCCM's to protect Geosynthetic Reinforced Soil structures. It focusses on the application where GCCMs can be used for the provision of a robust facing element to prevent vandalism, animal damage and UV degradation, if needed, of geosynthetic reinforced wrap faced structures. The characteristics and properties of GCCMs relevant for the application are reviewed and compared with traditional solutions to determine when they can be used to protect Reinforced Soil structures.

Keywords: Reinforced Soil; GCCM;

1 INTRODUCTION

The use of GCCMs in civil and geotechnical engineering has expanded considerably in recent years to provide erosion control solutions for a number of applications. Rather than replace existing erosion control geosynthetics such as Turf Reinforcement Mats (TRM's) which improve the resistance of vegetation to erosion, GCCMs are used as an alternative to conventional concrete, such as poured, precast and sprayed solutions. They are used when higher levels of protection are required than TRM's can offer, or when vegetation needs to be prevented from establishing in order to avoid long term maintenance issues. GCCMs are commonly being used in conjunction with conventional geosynthetics to provide a complete project solution, one such application is in the design of Reinforced Soil Structures (RSS).

The code of practice and standards for Reinforced Soil include several references to the use of sprayed concrete in RSS applications and designs, such as in BS8006-1:2010+A1:2016 Code of practise for strengthened/reinforced soils and other fills, as a hard superficial facing (7.5.4.4) and BS EN 14475:2006 Execution of special geotechnical works – Reinforced fill, as a cover to steel welded wire mesh facings (C.2.2.2) and to reduce the risk of vandalism and fire for wrapped around geosynthetic structures (Tables C.10 and C.11). Here we will consider the properties of GCCMs that may enable them to be used as an alternative to conventional concrete in these applications.

2 GCCM PROPERTIES

The recently published ASTM D8058-17 defines GCCMs as *'a factory-assembled geosynthetic composite consisting of a cementitious layer contained within a layer or layers of geosynthetic materials that becomes hardened when hydrated'*.

As shown in Figure 1, they typically consist of 3 layers: - A fibrous top surface that wicks water into the central layer, which is composed of a dense, 3-dimensional fibre reinforced matrix filled with a cementitious blend that has a high early strength gain. The hardened central layer acts to protect a bottom waterproof polymeric layer.

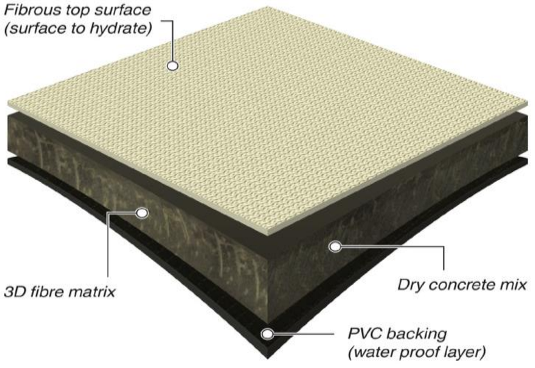

Figure 1. Section of a GCCM courtesy of Concrete Canvas Ltd.

The layers act to contain the cementitious blend during transport and installation, ensuring a consistent density of cement throughout the material and control of the water: cement ratio on hydration. Properly manufactured GCCMs cannot be over hydrated as they will fully set underwater, which greatly facilitates hydration on site by removing the need for careful water: cement ratio control. ASTM D8030-16 specifies the practice to prepare GCCM samples for testing of index properties by hydration of the GCCM through full immersion.

In the uncured state, GCCMs like other extensible reinforcing geosynthetics can be evaluated using tensile strength as one of the standard index tests. GCCM physical properties change with the addition of water and in service the GCCM becomes a thin rigid element. Once cured, GCCM's performance is better evaluated by a flexural bending test, which considers flexural strength.

2.1 Flexural Strength

Flexural strength is the primary characteristic considered when a GCCM is used as a facing element to a Reinforced Soil Structure. As a suitable assessment of a GCCM's tensile and compressive properties, ASTM D8058 sets out a 3-point bending test to assess and compare GCCM product performance. A typical stress/displacement graph is shown in Figure 2.

Test results demonstrate a semi ductile failure in 3 phases. 1st, the initial elastic phase reaches up to about 4MPa before the initial crack of the material. The GCCM then ruptures in a saw tooth fashion of progressive concrete failure and fibre loading, and at final rupture the fibres themselves begin to fail. This semi ductile failure has practical benefits, particularly in areas of differential settlements or ground heave, as the GCCM can crack and deform locally. The PVC membrane is more elastic and is therefore still protected by the protective cover layers of the composite. The test is designed to both demonstrate and be used for manufacturers quality control, as a higher initial breaking load at the 1st phase demonstrates a dense, high performance concrete that is well constrained in the GCCM. Poor quality cement blends and an inconsistent density would be reflected in lower initial breaking loads. Material with an initial breaking load lower than 4MPa does not have the same resilience to differential ground movement and is more likely to disintegrate over time. A higher flexural strength before the first break is therefore preferable.

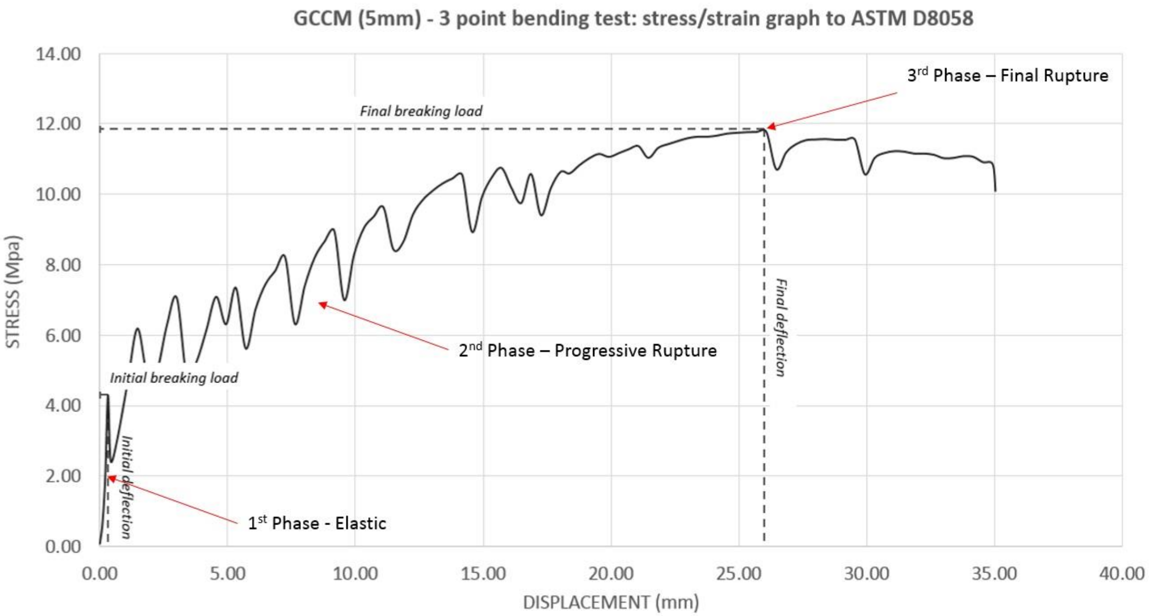

Figure 2. Typical stress-strain graph for a GCCM, data courtesy of Concrete Canvas Ltd

2.2 Abrasion

One of the most popular GCCM uses is to replace concrete in channel lining applications and is therefore subject to scour from sedimentation in water flow. When used as a facing to RSSs, the surface of the GCCM may be subject to similar scour when used to protect RSS flood bunds or line the face of reinstated canal/river side slopes, but can also be subject to wearing by animals attempting to burrow through the GCCM. Abrasion resistance is therefore an essential characteristic of a GCCM when used to protect RSSs. The fibre reinforced concrete component of GCCMs provides the primary abrasion resistance and as such the materials need to be tested to standards outside the scope of geosynthetics. A simple abrasion test using a rotary platform abrader to ASTM C1353 quantifies the loss in GCCM thickness over a number of abrasive cycles. A low material loss (less than 0.2mm/1000 cycles) represents good abrasion resistance; a higher material loss represents poor resistance to abrasion. Testing on the Concrete Cloth GCCM demonstrates abrasion in two stages. Initially, the top surface fibres which contain some cement wears at a rate of 0.5mm/1000 cycles, a similar rate to a 20MPa (2400psi) Quikcrete concrete as illustrated by the comparable gradient of the best fit lines in Figure 3 below. In the second stage of Concrete Cloth abrasion, the dense, high performance cement blend within the GCCM fibre matrix is worn. The abrasion resistance at this stage is much higher at 0.1mm/1000 cycles. This is slightly better resistance than a high performance, 64MPa (9300 psi) self compacting Portland Cement concrete at 0.15mm/1000 cycles, which is again illustrated by the slightly shallower gradient of the reinforced cement surface wearing best fit line in Figure 3. The test data demonstrates that GCCM fibre reinforced cementitious layers can provide excellent abrasion resistance similar to high performance concretes. Importantly, the fibre matrix in a GCCM ensures that when the GCCM is worn, the material remains intact and does not spall as in thin concrete samples. This is shown in the Quikcrete sample subject to 4700 abrasion cycles in Figure 3.

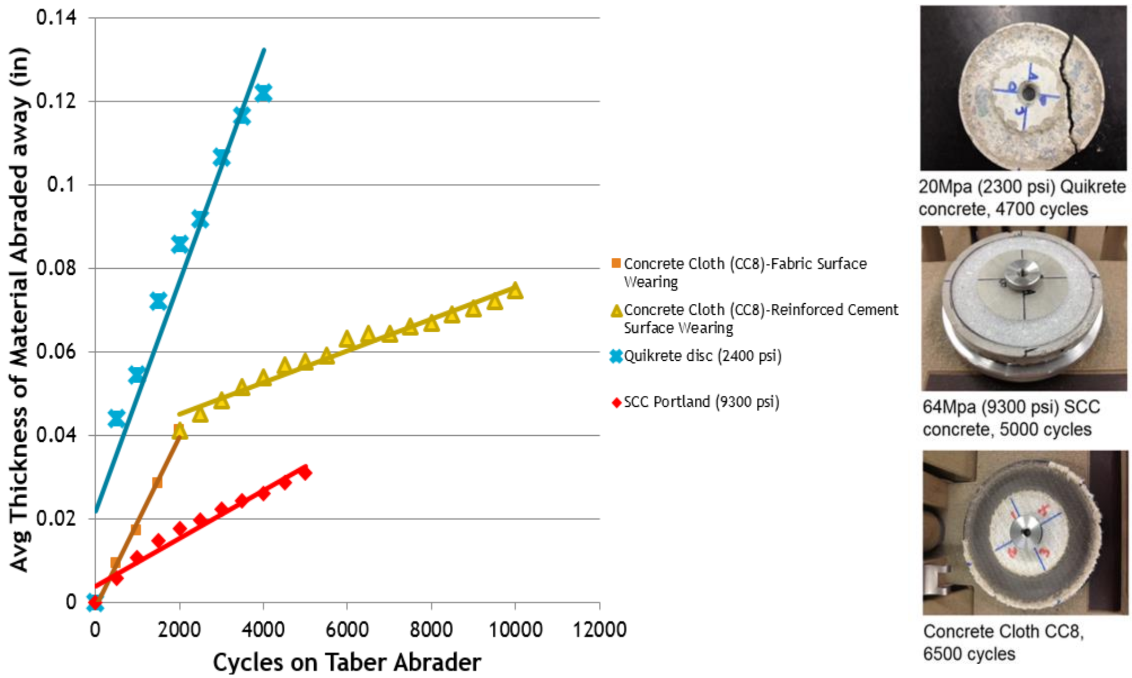

Figure 3. Abrasion resistance behavior of typical GCCM and samples after abrasion cycles. Data courtesy of Milliken Infrastructure.

2.3 Permeability

Permeability control is essential in protecting RSSs from excessive water infiltration and saturation of the reinforced soil block. The permeability of a GCCM is typically governed by the polymeric PVC backing layer and the overlying fibre reinforced matrix can be considered to act as the protection layer. Typical coefficients of permeability for the polymeric backing layer range from $k = 10^{-8}$ m/s for standard GCCM materials to $k=10^{-12}$ m/s for specialist containment GCCM composites known as Geosynthetic Cementitious Composite Barriers (GCCBs). Adjacent sheets of GCCM do not self adhere so the permeability of a GCCM structure is dependent on the method of joining the sheets together. A shingled joint with screws installed to ASTM D8173 provides a permeable joint, but for RSS face protection applications where high ground water levels are anticipated, weepholes can be installed through GCCM otherwise impermeable facing layers to allow groundwater release and avoid groundwater build up pressures behind the GCCM face cover.

For applications where the ingress of water needs to be prevented such as for flood bunds, permeability of the shingled screwed joint can be reduced by combining with adhesive sealants, or by overlapping joints and heat bonding to provide a high impermeability, non-penetrative jointing method. The specification for jointing is dependent on the type of GCCM material, the application and required joint permeability based on ASTM D8173 and the GCCM Manufacturers guidance.

The properties discussed in the sections above provide practical benefits when considered in RSS facing design as reviewed in more detail below.

3 FACING TO REINFORCED SOIL SLOPES

BS EN 14475:2006 specifies a number of possible facing solutions for RSSs including, but not limited to, precast concrete modular blocks and panels, wire/steel mesh and geosynthetic wrap around. For reinforced slopes, facings can vary from temporary erosion blankets for shallow slope, up to 45 degree face angle, with no wrap geosynthetic construction requirement, to steeper slopes with face angles greater than 45 degrees, that require wrapped geosynthetic reinforcement under or over temporary or permanent erosion control blankets and geotextiles, or covered by hard superficial facings (e.g. shotcrete, concrete panels).

Geosynthetic wrap faced structures are commonly specified for RSS construction due to the reduced construction costs over concrete and wire/steel mesh facing systems. Although most geosynthetic reinforcement, such as high density polyethylene (HDPE) geogrids, that form the structural component of the wrap face are UV resistant due to the addition of carbon black in their manufacturing process, it is the majority of secondary geosynthetic components behind the geogrid wrap at the face, that are used to contain the soil until vegetation is established, that will unlikely withstand permanent UV exposure.

Vegetation typically provides sufficient protection to geosynthetic elements from UV resistance. However, establishing vegetation cover on steep slopes is not always possible and depends on a number of factors including but not limited to: final slope face angle, orientation/exposure to sunlight, quality of topsoil behind the wrap face and irrigation. Seasonal weather changes can also prevent year-round vegetation growth. Other factors that could affect geosynthetic durability include damage from wildlife or vandalism.

When vegetation does not establish or if the structure is damaged, permanent repair solutions need to be considered in order to prevent further degradation of the geosynthetic structure face and its eventual propagation into the integrity of the rest of the reinforced soil structure, if left unrepaired. These could be in the form of concrete panels clipped or nailed to the slope, stone pitching, or by applying shotcrete. Concrete panel and stone pitching solutions are expensive and require careful design and construction to suitably mechanically connect into the wrap faced structure. Shotcrete applications require protection of existing infrastructure to prevent rebound during installation. Sprayed concrete is also prone to cracking during settlement of the reinforced soil structure. Both solutions require extensive temporary construction enabling works like scaffolding.

GCCM's can be used as a permanent facing option to protect unvegetated or damaged wrap faced reinforced soil structures, replacing conventional concrete solutions. The GCCM can be draped over the geosynthetic wrap face and anchored along the perimeter edges to prevent wind and water ingress. The roll applied GCCM is lighter and easier to handle than precast elements, minimises or eliminates the need of temporary scaffolding for construction and as discussed in section 2.1, its flexural strength allows it to accommodate any potential reasonable settlement or movement of the reinforced soil mass. Its flexible nature prior to hydration also allows for the installation of drainage weep holes during installation to allow for the effective drainage of any groundwater to freely discharge out of the RSS structure. GCCMs have been used to protect geosynthetic wrap slopes and walls worldwide. Three case studies of such applications are summarised below.

Southeast area, SC, USA. A steep geotextile reinforced slope on a landfill site was initially designed with a soil and vegetation cover. However, due to rapid degradation of the geotextile wrap face, an immediate permanent facing solution was required. 750 square meters of GCCM material was applied in three days, including creating toe drainage to divert water runoff and prevent saturation of foundation soils (see Figures 4–6). The primary benefits in using the GCCMs included the speed and ease of installation over conventional solutions which would have taken several weeks to mobilise and install.

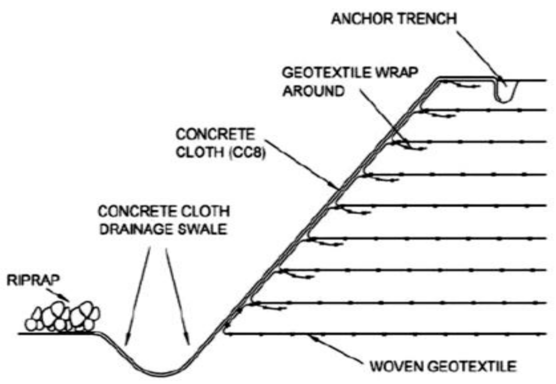

Figure 4. Proposed cross section of GCCM protection to RSS. Courtesy of Milliken & Co

Figure 5. GCCM installation over wrap faced RSS. Courtesy of Milliken & Co

Figure 6. Completed GCCM facing with toe drain. Courtesy of Milliken & Co

Reinforced soil wall facing, Oceania. A temporary geosynthetic reinforced soil bund wall (inner face vertical, outer face sloped) required a facing solution to transform it to a permanent structure. The reinforced soil slopes were constructed with uniaxial high density polyethylene (HDPE) reinforcing geogrids, as shown in Figure 7. The foundation and bottom courses of geogrid reinforcement were faced with concrete segmental blocks. Above this the primary geogrid reinforcement was wrapped around to form the facing, with the free end of the upper geogrid wrap connected to the next reinforcement layer using a bodkin joint. Although the HDPE uniaxial geogrids are UV resistant, the geotextile liner installed to the inside face to prevent loss of fill trough the facing could only offer soil containment temporarily for the short life of the structure, which satisfied the original temporary nature of the structure.

Figure 7. Wrap faced bund requiring permanent protection. Courtesy of Concrete Canvas Ltd.

However, the Clients' requirements changed and they needed to keep the structure in place permanently. Originally, they had hoped that vegetation would establish over time, but after 8 years in service they realised that vegetation could not be maintained all year around and through all seasons resulting in the facing geotextile that was placed under the UV-resistant geogrids being susceptible to UV degradation. Birds were also damaging the same geotextile by burrowing in the structure. Shotcrete was used as a temporary filler due to local face deformation caused by the damage but was never considered viable as a permanent facing due to the risk of cracking from cyclic temperature and moisture changes. 3,200 square meters of GCCM material was applied to protect the entire bund, secured to the vertical bund face using polymer earth percussion anchors and mechanically secured to a segmental block MSE Wall at the toe (see Figures 8-9). The GCCM has prevented further UV degradation and bird burrowing damage of

Figure 8. Placing GCCM to protect bund structure. Courtesy of Concrete Canvas Ltd.

Figure 9. Installed GCCM to protect wrap faced bund. Courtesy of Concrete Canvas Ltd.

the geotextile under the HDPE UV-resistant geogrid facing material and due to its abrasion resistance as discussed in section 2.2, has stopped animals nesting, ensuring the longevity of the bund structure.

Isle of Mull, Scotland. Geogrid stabilised flood bund. As part of a new fish hatchery design, the location of the header tanks needed to be sited in a location that was prone to flooding and the design required the concrete foundation slab to be raised by 1650mm to prevent submersion in anticipated flood events. The designer specified a geogrid stabilised soil bund to increase the height of the slab, as shown in figure 10. The geogrid stabilised soil structure was composed of site won gravels, stabilised with polymeric geogrid at 450mm centres. The shallow slope face angle was designed at 45 degrees, requiring a non wrap face geosynthetic construction.

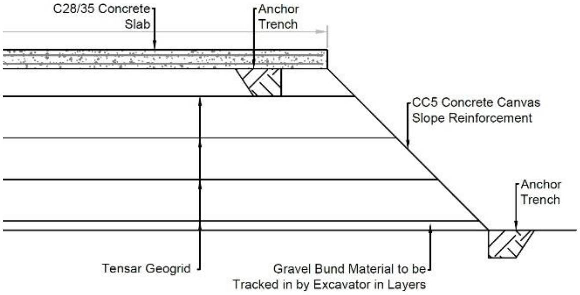

Figure 10. Proposed flood bund cross section with GCCM facing. Courtesy of Concrete Canvas Ltd.

A vegetated facing to the flood bund was considered, but was ruled out as the anticipated flood water flow velocities and flood durations would exceed the capabilities for vegetation to withstand the scour and erosion forces in such events (based on CIRIA Report No 116, Design of reinforced grass spillways). A hard superficial facing was therefore required. Shotcrete was considered but discounted as any movement of the bund could cause it to crack and enable water through the face and erode the reinforced soil. A GCCM was chosen due to its flexural strength

Figure 11. Sand placed on face of RSS prior to placing GCCM. Courtesy of Concrete Canvas Ltd.

and semi ductile failure mode as discussed in section 2.1, enabling the facing to accommodate any potential movement in the geogrid stabilised soil bund. A sand layer was compacted on the face of the slope to provide a smooth surface on which to install the GCCM (see figures 11-12).

Figure 12. Completed RSS faced with GCCM.. Courtesy of Concrete Canvas Ltd.

The permeability of the GCCM layers were reduced sealing the overlaps with adhesive sealant before screwing at 50mm centres to provide a high strength, reduced permeability joint as discussed in section 2.3. 280 square metres of GCCM were supplied by ferry to the site and installed in 3 days, providing the client with considerable logistical and programme savings over installing conventional hard superficial facings.

4 CONCLUSION

The physical and practical properties of GCCMs enable them to be incorporated in RSS design to replace conventional concrete techniques. For existing geosynthetic wrap faced structures that have not been or cannot be vegetated or are subject to physical or UV damage, GCCMs can be used as a protective facing to ensure the longevity of the geosynthetic wrap faced structure. GCCMs can also be specified in the design of new RSSs, particularly for flood bunds when vegetated facings cannot provide the required erosion resistance and a low permeability hard superficial facing is needed. GCCMs have a distinct advantage over poured or sprayed concrete in these applications as they can accommodate acceptable post construction movements and settlements, providing the performance of conventional concrete solutions, but with the flexibility of geosynthetics.

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