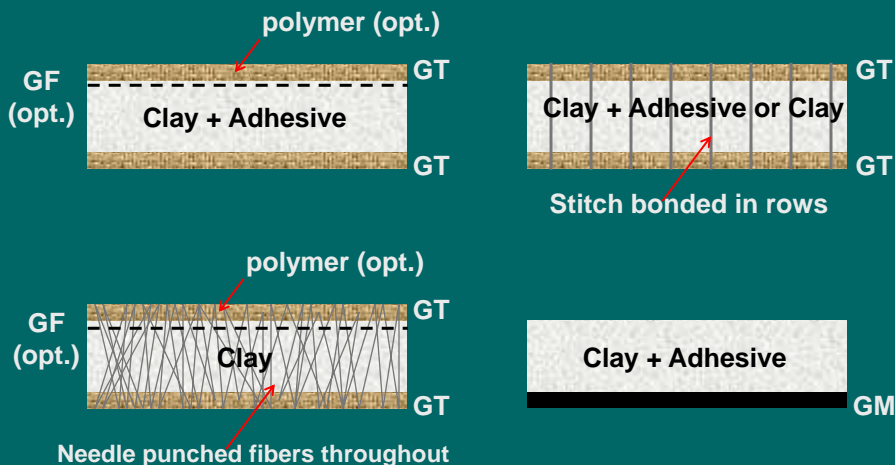


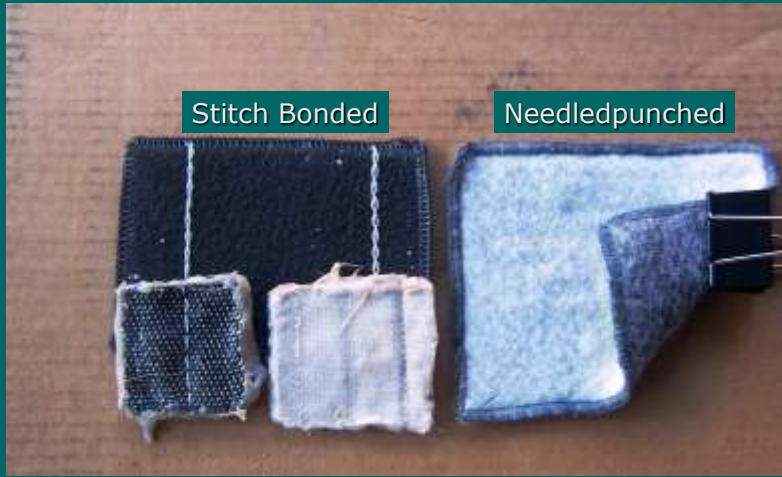
GRI-GCL3 Specification

Geosynthetic Clay Liners (GCLs)

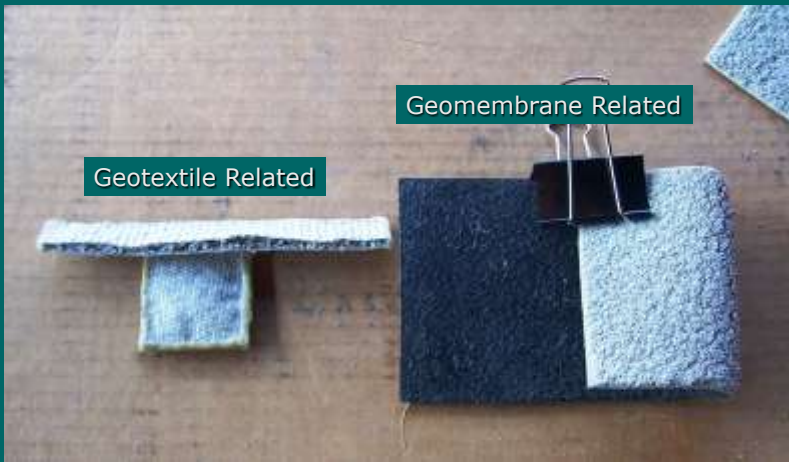
- ◆ for reinforced and nonreinforced GCL products
- ◆ addresses GT-related, GT Polymer Coated, and GM and GF-related in each category
- ◆ tests included on basic clay, GT, GM and GF
- ◆ tests also included on as-manufactured GCL
- ◆ in addition includes durability tests and criteria
- ◆ our most complicated specification-to-date

Cross-sections of most common GCLs





Reinforced GCLs



Nonreinforced GCLs

Geofilm Related



Reinforced (as shown) or Nonreinforced

Polymer-Coated



Reinforced or Nonreinforced

Listed Spec Tests and Properties

Component Tests

<u>bentonite</u>	<u>GTs</u>	<u>GM/GF</u>
1. swell index	3. cap weight	6. thickness
2. fluid loss	4. carrier weight	7. density
	5. coating weight	8. strength

Composite GCL Tests

9. composite weight	12. tensile strength
10. bentonite weight	13. peel strength
11. moisture content	14. permeability or flux

Durability Tests

15. alkaline permeant	17. oven and UV aging of GM
16. oven aging of GT	18. oven aging of GF and polymer

Direct Shear Testing

- ◆ this is not felt to be a MQC test; as such, it is not included in the spec
- ◆ although it is critically important for internal, upper and lower interfaces
- ◆ it's a design (performance) test and follows ASTM D6243
- ◆ perhaps related to the peel test, but correlations are not established

1. Swell Index

- ◆ for the as-received bentonite
- ◆ follows ASTM D5890
- ◆ 2.00 gms bentonite in 100 ml of deionized water for 16 hrs.
- ◆ minimum swelling of top of settled clay must be 24 ml/2g
- ◆ tested once per 50 tonnes minimum



bentonite in a graduated cylinder to measure amount of swelling

2. Fluid Loss

- ◆ for the as-received bentonite
- ◆ follows ASTM D5891
- ◆ bentonite slurry prepared in a mixer
- ◆ 6% solids slurry on filter paper
- ◆ pressurized at 700 kPa in filter press
- ◆ liquid collected at base of press
- ◆ maximum value is 18 ml in 15 min.
- ◆ tested once per 50 tonnes minimum



3, 4, & 5 – Cap, Carrier, Coating Weights

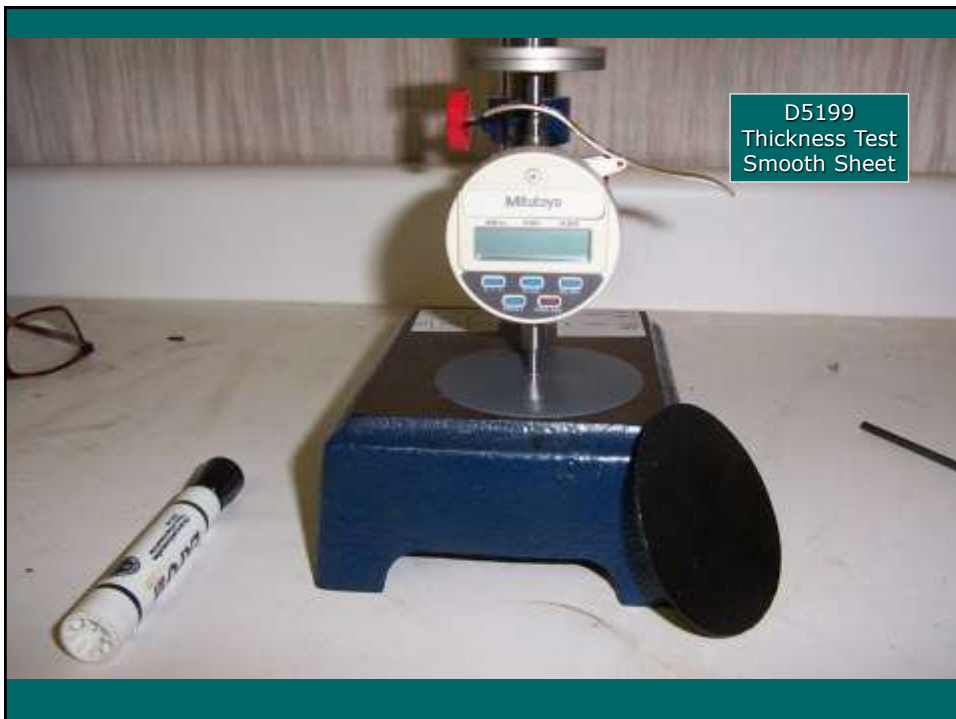
- ◆ proper term is “mass per unit area”
- ◆ covers all products; GT, GT polymer, GM, and GF
- ◆ follows ASTM D5261
- ◆ straightforward test performed on the GSs before manufacturing the GCL
- ◆ tested every 20,000 m² minimum, except for polymer coating being every 4,000 m²

Weighing specimen
for mass per unit area



6. Thickness of GM and GF

- ◆ follows ASTM D5199
- ◆ dead weight micrometer with flat tip
- ◆ 10-specimens across roll width
- ◆ take average and compare to spec
- ◆ tested every 20,000 m² minimum



7. Density of GM and GF

- ◆ uses ASTM D1505 (gradient column) or ASTM D792 (displacement)
- ◆ min. ave. of 3 tests for D1505
- ◆ min. ave. of 2 tests for D792
- ◆ D1505 is the more accurate test
- ◆ value ≥ 0.920 g/cc (resin is lower)
- ◆ tested every 20,000 m² minimum





8. Break Strength of GM and GF

- ◆ GM strength (MD & XMD) uses ASTM D6693 test method
- ◆ specimens are dogbone shaped
- ◆ GF strength (MD) uses ASTM D882
- ◆ specimens are 25 mm wide strips
- ◆ tested every 20,000 m² minimum

ASTM D6693
Test Specimens



D6693
"Dogbone"
Test in Progress



ASTM D882 Narrow (25 mm wide) Strip Tensile Test

9 & 10 – Mass of GCL and Bentonite

- ◆ its “mass per unit” area using ASTM D5993
- ◆ min. specimen size is 100 by 100 mm
- ◆ oven-dry specimen at 110°C
- ◆ take care not to loose clay
- ◆ weigh to obtain mass of GCL composite
- ◆ subtract GS mass(es) to get mass of dry bentonite
- ◆ use average of five specimens
- ◆ tested every 4,000 m² minimum



11. Moisture Content

- ◆ can be measured directly by removing bentonite, weighing, then drying in an oven, weighing again

$$w(\%) = (W_{\text{water}}/W_{\text{dry clay}}) 100$$

- ◆ alternate is to use ASTM D5993

$$w(\%) = \left[\frac{\left(\frac{M_i}{A} \right) - m_{\text{GCL}}}{m_{\text{clay}}} \right] 100$$

where

M_i = initial mass of GCL specimen

m_{GCL} = mass of dry GCL

m_{clay} = mass of dry bentonite

A = area of specimen



Extremely High Moisture Content
Bentonite



As-Received (Upper Samples) vs.
Fully Hydrated (Lower Samples)

Spec calls for 35% maximum value;
no lower limit

12. Tensile Strength of GCL

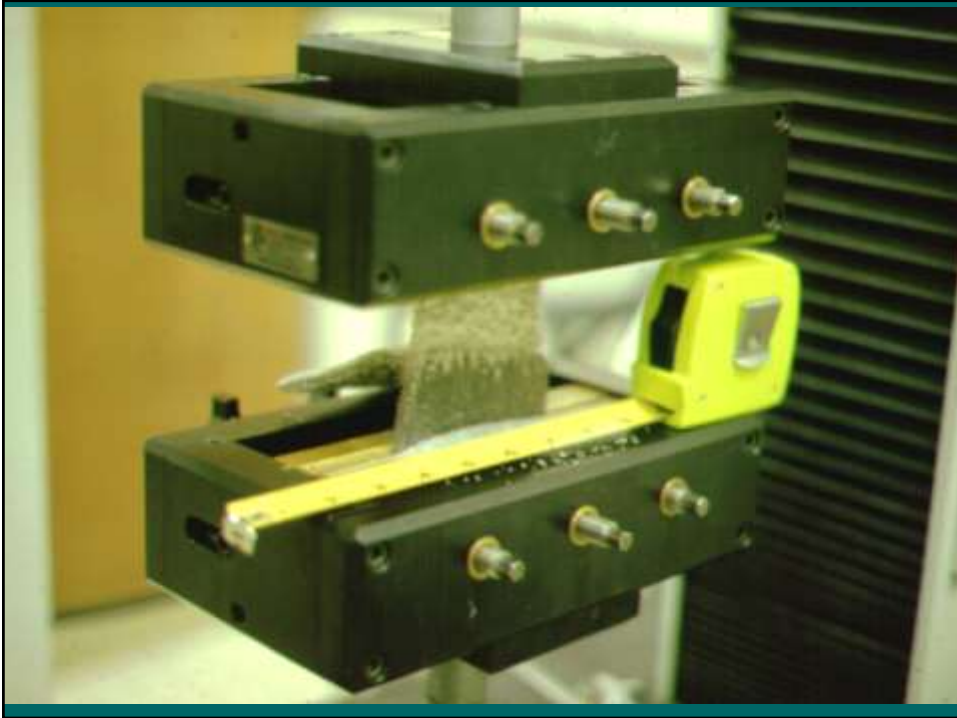
- ◆ follows ASTM D6768 (MD only)
- ◆ 100 mm wide specimens by 200 mm long
- ◆ tested at 300 mm/min
- ◆ five specimens across roll width
- ◆ minimum value is 4.0 kN/m (all GCLs)
- ◆ tested every 20,000 m² minimum



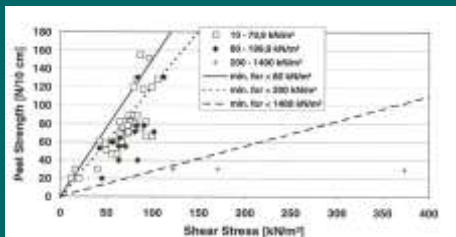
ASTM D6768 Tension Test In-Progress

13. Peel Strength

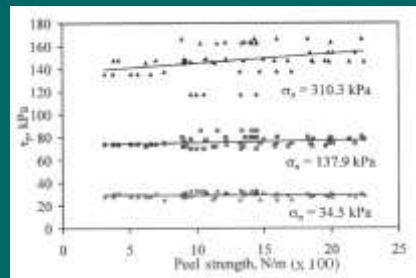
- ◆ for reinforced GCLs (needled or stitched)
- ◆ follows ASTM D6496
- ◆ 100 mm wide by 200 mm long specimens
- ◆ tested at 300 mm/min
- ◆ report average strength over 100 mm peel (from 25 to 125 mm length)
- ◆ average of 5-tests \geq 360 N/m (2.1 lb/in.)
- ◆ tested every 4000 m² minimum



Peel-to-Shear Correlations



(a) After von Maubeuge, et al., GCL Conference, 2002



(b) After Zornberg, et al., JGGED, 2005

14. Permeability or Flux of GCL

- ◆ follows ASTM D5887
- ◆ only applicable for GT-related GCLs
- ◆ cell pressure = 550 kPa; back pressure = 515 kPa and hold for 48 hr
- ◆ deionized water flow at 530 kPa
- ◆ measure flux when inflow \approx outflow; remove specimen; measure thickness; calculate permeability coefficient (k)
- ◆ test every 25,000 m² minimum



15. Permeability Using Alkaline Permeant

- ◆ follows ASTM D6766
- ◆ essentially same as D5887, but uses alkaline solution (0.1 M CaCl_2)
- ◆ tests at 35 kPa and at 500 kPa
- ◆ results in significant increase in “k”
- ◆ test at least every year



16 & 18 – Oven Aging of GT, GM and GF

- ◆ assessment of thermal stability of antioxidants (AOs) in formulation
- ◆ follows ASTM D5721
- ◆ forced air oven at 85°C
- ◆ strength retained $\geq 65\%$ after 90 days exposure
- ◆ frequency is at least yearly



17 - Ultraviolet Aging of GMs

- ◆ assessment of UV stability of the AOs and CB in the formulation
- ◆ uses a laboratory weatherometer
- ◆ follows ASTM D7238
- ◆ called “ultraviolet fluorescent device”
- ◆ 20 hr. UV cycle at 75°C, then 4 hr. condensation at 60°C
- ◆ HP-OIT \geq 50% ret. after 1600 hrs.
- ◆ frequency is at least yearly



Commentary on GRI-GCL3

- ◆ its very complex and intricate spec
- ◆ necessary due to variety of products
- ◆ durability aspects are critical
- ◆ moisture content omitted (at present)
- ◆ "essentially needle free" is in text
- ◆ expect changes; latest version is on GSI Web Site <geosynthetic-institute.org>

GRI-GCL3 Spec - SI (Metric) Units

Table 1(a) - Specifications for Geosynthetic Clay Liners (GCLs)

Property	ASTM Test Method	Emulsified GCL			Non-Emulsified GCL			Testing Frequency
		GE-Related	GT Polymer Coated	GM-GF Related	GS-Related	GT Polymer Coated	GM-GF Related	
Unit Weight								
total (g/cm ²)	D1585	24	24	24	24	24	24	50 tests
backfill (g/cm ²) ⁽¹⁾	D1585	15	15	15	15	15	15	50 tests
Geosynthetic Fabric								
cap fabric (nonwovens)-mass unit area (g/m ²) ⁽²⁾	D1281	100	100	100	100	100	n/a	10,000 m ²
cap fabric (nonwovens)-mass unit area (g/m ²) ⁽²⁾	D1281	100	100	100	100	100	100	10,000 m ²
center fabric (nonwovens)-mass unit area (g/m ²) ⁽²⁾	D1281	240	240	240	100	100	n/a	10,000 m ²
center fabric (nonwovens)-mass unit area (g/m ²) ⁽²⁾	D1281	100	100	100	-	-	-	10,000 m ²
coating - mass unit area (g/m ²) ⁽²⁾	D1281	n/a	100	n/a	n/a	100	n/a	4,000 m ²
Dimensions								
thickness (mm)	D1184 D1094	n/a	n/a	0.40-0.50(10)	n/a	n/a	0.40-0.75(10)	10,000 m ²
density (g/cm ³)	D1535-D1792	n/a	n/a	0.92	n/a	n/a	0.92	10,000 m ²
tear & tensile strength, MD & MTD (kN/m)	D4630	n/a	n/a	n/a	n/a	n/a	0.0	10,000 m ²
tear & tensile strength, MD (kN/m)	D4632	n/a	n/a	1.5	n/a	n/a	1.5	10,000 m ²
GCL Characteristics								
mass of GCL (g/m ²) ⁽³⁾	D1585	4000	4010	4100	4000	4010	4100	4,000 m ²
mass of fibrous fabric (g/m ²) ⁽³⁾	D1585	3700	3700	3700	3700	3700	3700	4,000 m ²
mass of center fabric (g/m ²) ⁽³⁾	D1585	37	37	37	37	37	37	4,000 m ²
tear strength, MD (kN/m)	D4630	4.0	4.0	4.0	4.0	4.0	4.0	10,000 m ²
tear strength, MTD (kN/m)	D4630	100	100	100	n/a	n/a	n/a	4,000 m ²
permeability (m/s) ⁽⁴⁾	D1087	5 × 10 ⁻¹¹	n/a	n/a	5 × 10 ⁻¹¹	n/a	n/a	21,000 m ²
flow (cm ³ /hr/cm ²) ⁽⁴⁾	D1087	1 × 10 ⁻⁹	n/a	n/a	1 × 10 ⁻⁹	n/a	n/a	21,000 m ²
GCL permeability (m/s) ⁽⁵⁾ (at 10 kPa)	D6708	1 × 10 ⁻⁹	n/a	n/a	1 × 10 ⁻⁹	n/a	n/a	ready
GCL permeability (m/s) ⁽⁵⁾ (at 100 kPa)	D6708	1 × 10 ⁻⁹	n/a	n/a	1 × 10 ⁻⁹	n/a	n/a	ready
Compressive Densities								
particle and void fractions (g/cm ³) (g/cm ³ strength retained)	See 1.8.2	03	03	n/a	03	03	n/a	ready
particle mass	See 1.8.3	n/a	n/a	GSI Spec ⁽⁶⁾	n/a	n/a	GSI Spec ⁽⁶⁾	ready
void fraction	See 1.8.4	n/a	03	03	n/a	03	03	ready

n/a = not applicable; n/a refers to this property.
 (1) These values are minimums (all others are maximums).
 (2) For bulk use and mass values for capacity the maximum GCLs, use, as the flow, mass contains a minimum amount of mass per unit area. The only applies to GM-GCL, except those that are applied to the other GCLs for the correct units as long as you to complete your operation.
 (3) Calculated value obtained from difference of total fabric to as stated below.
 (4) Test values for overall permeability, based on the total permeability, that is the quality.
 (5) Mass of the GCL, and permeability, measured after one day after the stated test method.
 (6) Value represents GCL permeability after permeation with a 1.1 M sodium chloride solution (11.1 g GCL in 1 liter water); permeability criteria see 1.8.3.
 (7) Value represents the maximum percent strength retained in use the as stated below value after one day at 80°C for 72 days.
 (8) Permeability values should follow the appropriate specifications for the permeability (gpm) i.e., GSI GCL-11 for HDPE, GSI GCL-12 for LDPE, or GSI GCL-13 for PP.

GCL3 - 11 of 12

Rev. 42 - 1/24/10

Table 1(b) – Specifications for Geosynthetic Clay Liners (GCLs)

Property	ASTM Test Method	Emulsified GCL			Non-Emulsified GCL			Testing Frequency
		GT-Related	GT Fabric Coated	GT-LD Related	GT-Related	GT Fabric Coated	GT-LD Related	
Clay (as received)								
moist. ashles (wet 2g)	D1580	24	24	24	24	24	24	30 tests/lot
ashles (wet) ⁽¹⁾	D1581	18	18	18	18	18	18	30 tests/lot
Geotextiles (as received)								
cap fabric (mass/area) - mass (wt area) (wt/yd ²) ⁽²⁾	D1281	3.0	3.0	3.0	3.0	3.0	max 3.0	25,000 yd ²
cap fabric (mass/area) - mass (wt area) (wt/yd ²) ⁽²⁾	D1281	3.0	3.0	3.0	3.0	3.0	3.0	25,000 yd ²
center fabric (mass/area) - mass (wt area) (wt/yd ²) ⁽²⁾	D1281	3.0	3.0	3.0	3.0	3.0	max 3.0	25,000 yd ²
center fabric (mass/area) - mass (wt area) (wt/yd ²) ⁽²⁾	D1281	3.0	3.0	3.0	-	-	-	25,000 yd ²
center fabric (mass/area) - mass (wt area) (wt/yd ²) ⁽²⁾	D1281	max	2.0	max	max	2.0	max	5,000 yd ²
Geosynthetic Clay Liner (as received)								
ashles ⁽¹⁾ (wet)	D1580-D1584	n/a	n/a	15-20.4	n/a	n/a	15-20.4	25,000 yd ²
density (g/cc)	D1551-D1762	n/a	n/a	0.92	n/a	n/a	0.92	25,000 yd ²
tear tensile strength, MD & TD (lb/in.)	D6485	n/a	n/a	n/a	n/a	n/a	54	25,000 yd ²
tear tensile strength, MD & TD (ft/lb)	D6485	n/a	n/a	14	n/a	n/a	14	25,000 yd ²
GCL (as installed)								
mass of GCL (lb/ft ²) ⁽³⁾	D1580	0.81	0.81	0.84	0.81	0.81	0.84	5,000 yd ²
mass of liner (lb/ft ²) ⁽³⁾	D1580	0.75	0.75	0.75	0.75	0.75	0.75	5,000 yd ²
mass of liner (lb/ft ²) ⁽³⁾	D1580	33	33	33	33	33	33	5,000 yd ²
tear strength, MD (lb/in.)	D6486	23	23	23	23	23	23	25,000 yd ²
tear strength (ft/lb)	D6486	2.1	2.1	2.1	1.0	1.0	1.0	5,000 yd ²
permeability ⁽⁴⁾ (cm/sec) "w"	D1537	1 x 10 ⁻¹¹	n/a	n/a	1 x 10 ⁻¹¹	n/a	n/a	10,000 yd ²
flow ⁽⁵⁾ (cm ³ /sec-cm)	D1537	1 x 10 ⁻¹¹	n/a	n/a	1 x 10 ⁻¹¹	n/a	n/a	10,000 yd ²
GCL permeability ⁽⁶⁾ (cm/sec) (max. at 7 ft/in.)	D6766	1 x 10 ⁻¹¹	n/a	n/a	1 x 10 ⁻¹¹	n/a	n/a	yearly
GCL permeability ⁽⁶⁾ (cm/sec) (max. at 70 ft/in.)	D6766 mod	1 x 10 ⁻¹¹	n/a	n/a	1 x 10 ⁻¹¹	n/a	n/a	yearly
Composite Liner (as installed)								
permeable and nonpermeable area ⁽⁷⁾ (% strength retained)	See 1.4.2	81	81	n/a	81	81	n/a	yearly
permeability	See 1.4.2	n/a	n/a	GCL Spec ⁽⁸⁾	n/a	n/a	GCL Spec ⁽⁸⁾	yearly
profile picture break ⁽⁹⁾ (% strength retained)	See 1.4.4	n/a	81	81	n/a	81	81	yearly

n/a = not applicable with respect to this property.

(1) These values are maximum. All others are minimums.

(2) For both cap and center fabric for mass-area emulsified GCLs, wet, in the office, must contain a water component of mass = 2.0 wt% for dimensional stability. This only applies to GT-GCL composite which are exposed to the atmosphere for several months or longer or so to mitigate peak separation.

(3) Calculated value obtained from difference of coated fabric to an uncoated fabric.

(4) Test value is the average permeability, corrected for measured permeability, based on profile.

(5) Mass of the GCL, and laminate is measured after stress during per the stated test method.

(6) Value represents GCL permeability after permeation with a 1.1 M sodium chloride solution (11.1 g CaCl₂ in 1 liter water); temperature criterion see 1.4.1.

(7) Value represents the minimum percent strength retained from the as-manufactured value after stress applied at 80°C for 30 days.

(8) Durability criteria should follow the appropriate specifications for the permeability used, i.e., GRI-GCL-1 for HDPE, GRI-GCL-1 for LLDPE or GRI-GCL-1 for GPE.