

## GRI-GM17 Specification Linear Low Density Polyethylene Geomembranes

- spec covers smooth and textured LLDPE
- thicknesses 0.50-3.00 mm (20-120 mils)
- formulated density  $\leq 0.939$  g/cc
- silent on flat die or blown film
- lists properties, test methods, test values and test frequencies
- covers twelve (12) properties

## Preliminary Comments

- definition of “formulation”  
The mixture of a unique combination of ingredients identified by type, properties and quantity. For LLDPE geomembranes a formulation is defined as the exact percentages and types of resin(s), additives and carbon black.
- regarding quantities referred to in spec  
90,000 kg = 200,000 lb  $\simeq$  1 railcar  
20,000 kg = 45,000 lb  $\simeq$  25 rolls of 1.5 mm (60 mil)  
9,000 kg = 20,000 lb  $\simeq$  10 rolls of 1.5 mm(60 mil)

### Physical Properties

1. thickness
2. density

### Mechanical Properties

3. tensile
4. modulus
5. tear
6. puncture
7. axi-symmetric

### Endurance Properties

8. CB content
9. CB dispersion
10. OIT
11. oven aging
12. UV resistance

## 1. Thickness

### (a) smooth sheet

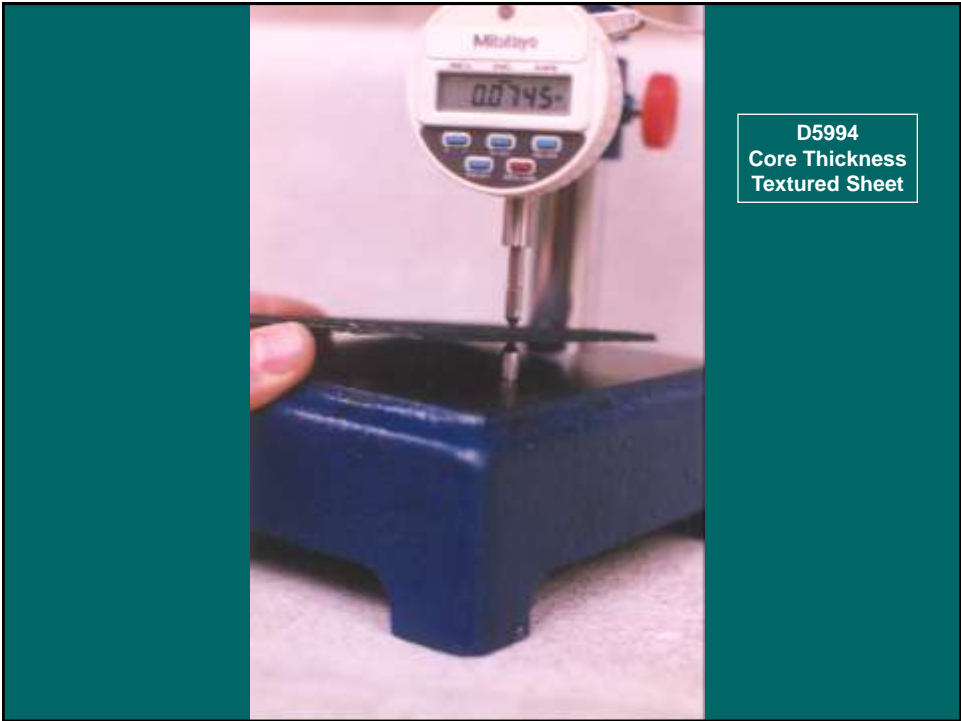
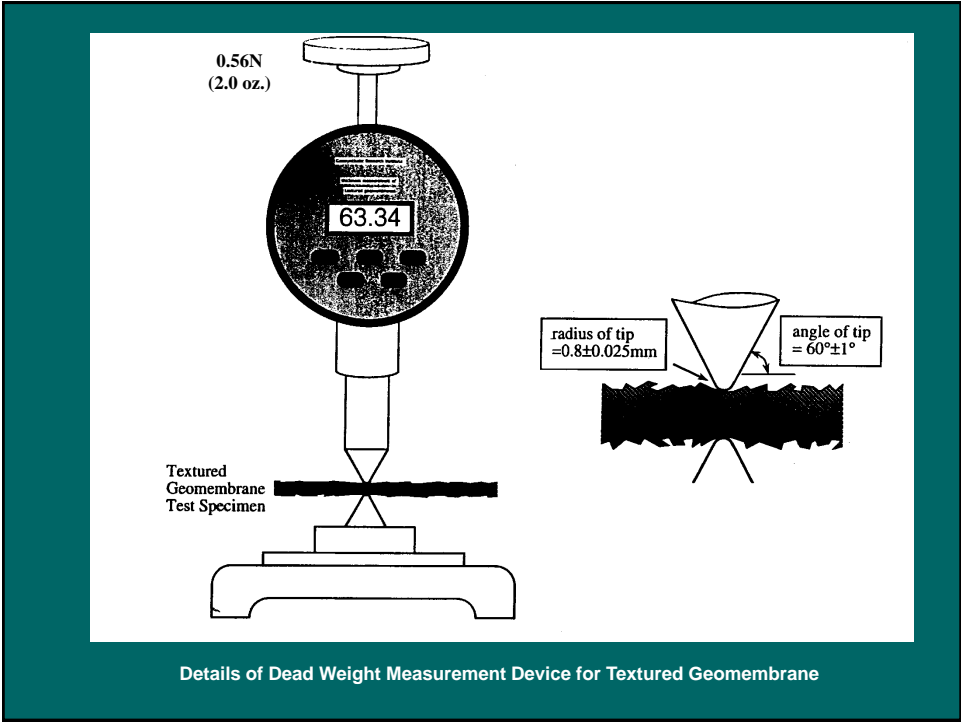
- follows ASTM D5199
- dead weight micrometer with flat tip
- 10-specimens across roll width
- required for each roll
- average must equal nominal
- lowest individual is  $-10\%$



D5199  
Thickness Test  
Smooth Sheet

## (b) textured sheet – core thickness

- follows ASTM D5994
- dead weight micrometer with tapered tip (screw micrometer)
- 10-specimens across roll width
- required for each roll
- average equal nominal -5%
- lowest individual is -15%



## (c) textured sheet – asperity height

- follows ASTM D7466
- uses a stylus to measure height
- 10 specimens across roll width
- required every 2<sup>nd</sup> roll
- alternate for double sided sheet
- min. ave.  $\geq 0.25$  mm (10 mil)

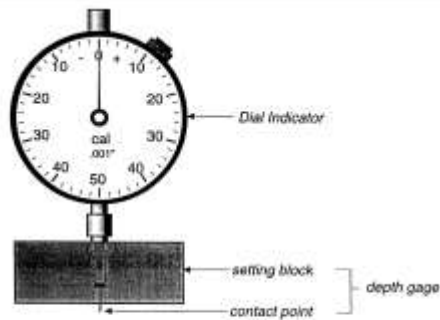


Figure 1 - The configuration of the asperity height test device (Federal Part No. 75P/W40812)

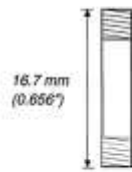


Figure 2 - Indicator Rack Extension (Federal # EZ 108)

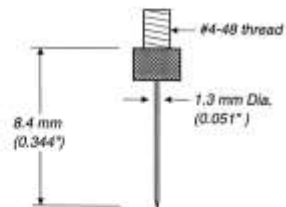


Figure 3 - The dimensions of the contact point (Federal # PT-2265)

## 2. Density

- 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  $\leq 0.939$  g/cc (resin is lower)
- each railcar: 90,000 kg or 200,000 lb





### 3. Tensile Properties

- uses ASTM D6693 Type IV
- min. ave. of 5 MD and 5 XMD
- yield is not addressed

Property	Smooth	Textured
break str.	27 MN/m <sup>2</sup> (3800 lb/in <sup>2</sup> )	11 MN/m <sup>2</sup> (1500 lb/in <sup>2</sup> )
break elong.	800%	250%

- every 9000 kg (20,000 lb)  $\approx$  10 rolls

ASTM D6693 Type IV  
Test Specimens



D6693 Type IV  
"Dogbone"  
Test in Progress

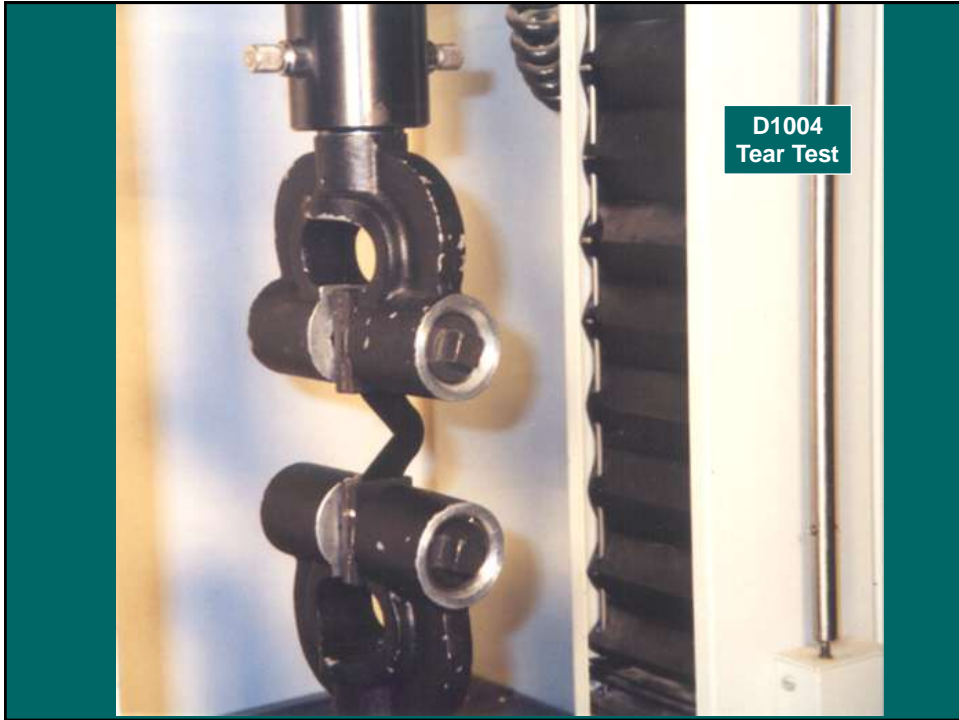


## 4. Modulus

- uses ASTM D6693 for data
- calculations via ASTM D5323
- measures slope of initial curve
- it's a maximum value
- $\leq 4200 \text{ N/mm}^2$  (60,000 lb/in<sup>2</sup>)
- its a per formulation value

## 5. Tear Resistance

- uses ASTM D1004
- called 90 deg. tear test
- min. ave. of 10 MD and 10 XMD
- lesser value  $\geq 100 \text{ N/mm}$  (550 lb/in)
- every 20,000 kg (45,000 lb)  $\simeq$  25 rolls



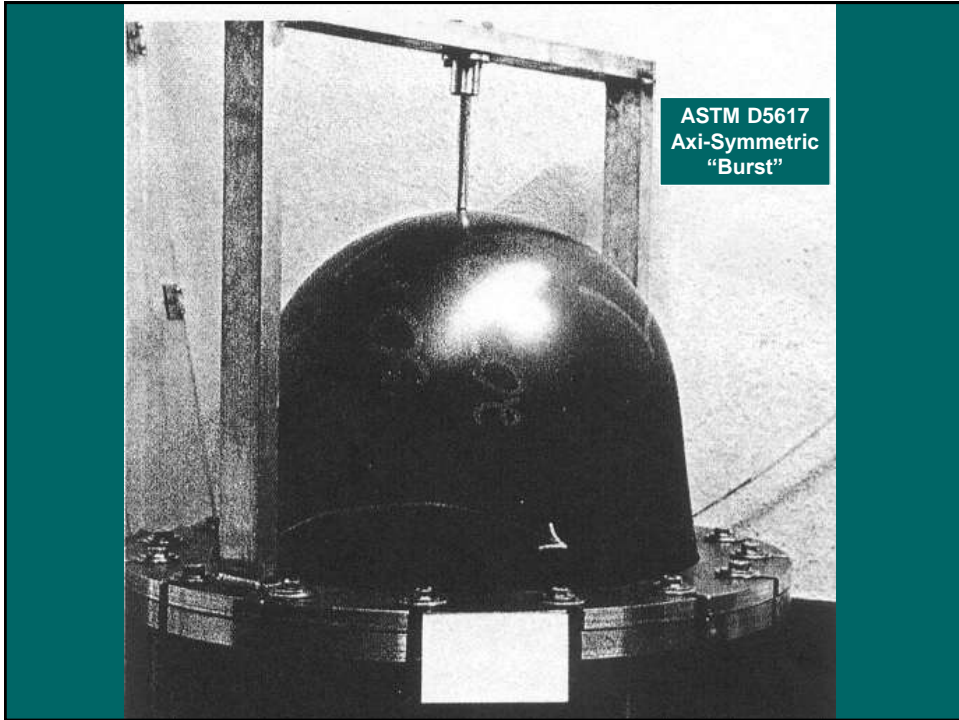
## 6. Puncture Resistance

- follows ASTM D4833
- called “pin” puncture
- min. ave. of 15-tests  
smooth  $\geq 250$  N/m (1400 lb/in)  
textured  $\geq 150$  N/mm  
(1100 lb/in)
- every 20,000 kg (45,000 lb)  $\simeq$  25 rolls



## 7. Axi-Symmetric Break Strain

- follows ASTM D5617
- it's a huge "burst" type of test
- simulates out-of-plane deformation
- measures pressure and deformation
- calculations give strength and strain
- strain (at break)  $\geq 30\%$
- required for each formulation



## 8. Carbon Black Content

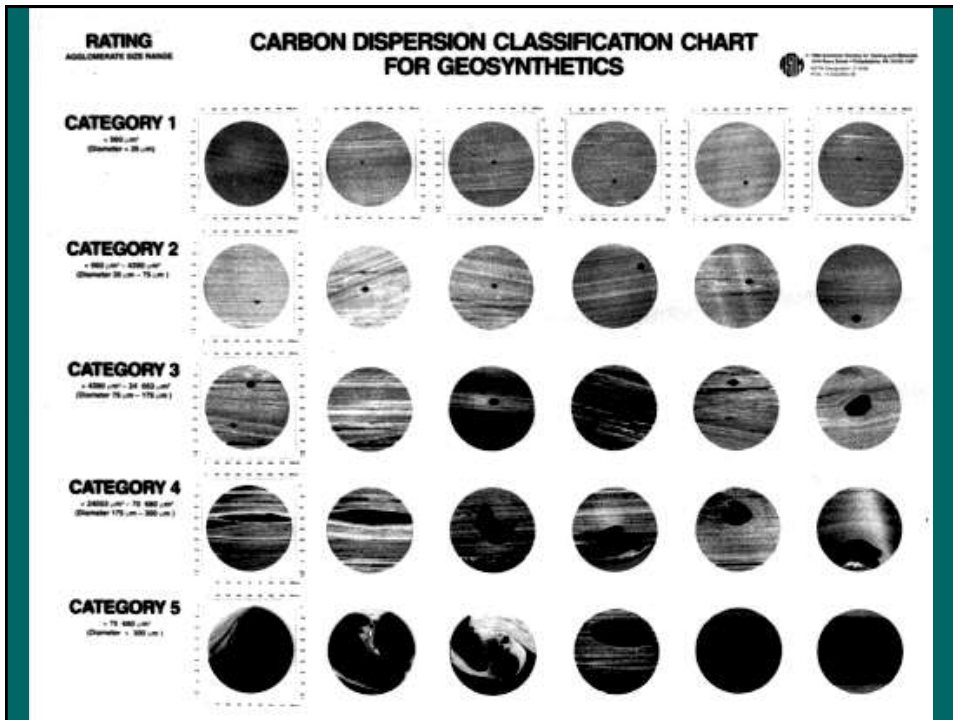
- follows ASTM D1603 (combustion boat placed in tube furnace)
- muffle furnace (D4218) or microwave O.K. if correlation is established
- ave. of two tests in 2.0 to 3.0% range
- every 20,000 kg (45,000 lb)  $\approx$  25 rolls



## 9. Carbon Black Dispersion

- follows ASTM D5596
- microtome section (8-15 mm thick)
- view under microscope at 100X
- 10 views are compared to chart
- 9 in Cat. 1 or 2; 1 in Cat. 3
- only considers “near spherical” shapes (this is not CB distribution)
- every 20,000 kg (45,000 lb)  $\approx$  25 rolls





## Commentary

- “dispersion” is concerned over CB agglomerates, i.e., flocs with no resin
- can lead to low tensile values or even stress crack initiation
- “distribution” is concerned with incomplete mixing
- leads to streaking with different shades of darkness but CB is dispersed
- distribution has not been shown to be a problem...

## 10. Oxidative Induction Time

- OIT is an indirect measurement of the amount of antioxidants

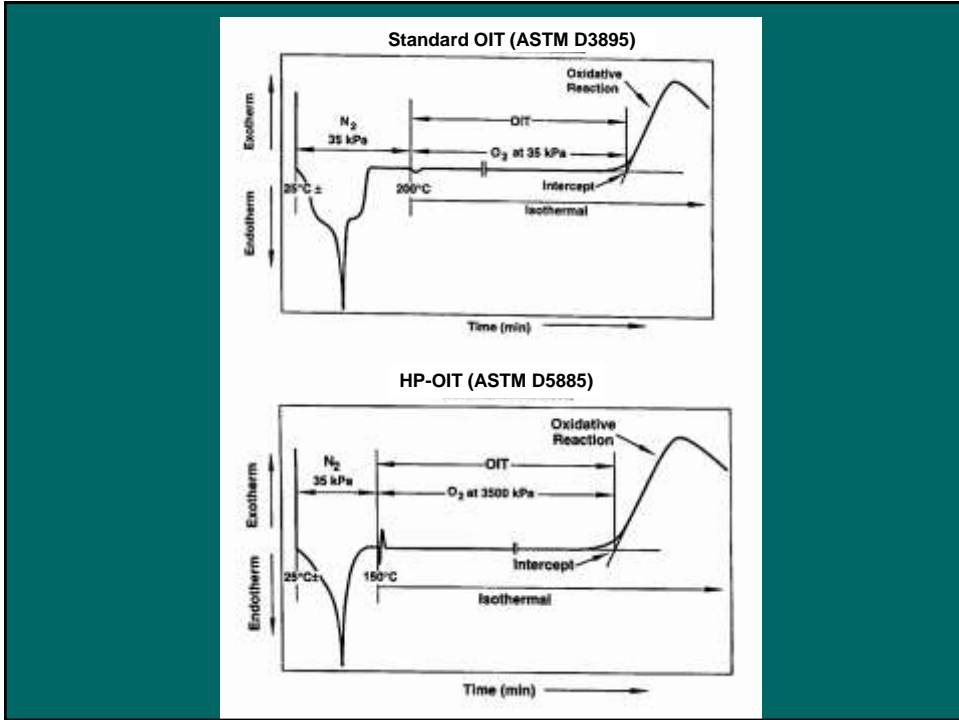
Item	Standard	High Pressure
ASTM	D3985	D5885
Specimen	≈ 2 mg	≈ 2 mg
Pressure	35 kPa (5 lb/in <sup>2</sup> )	3500 kPa (500 lb/in <sup>2</sup> )
Temperature	200°C in N <sub>2</sub> ; 1 min. dwell; switch to O <sub>2</sub>	150°C to N <sub>2</sub> ; 1 min. dwell; switch to O <sub>2</sub>
Spec Value	≥ 100 min.	≥400 min.

- Frequency is each railcar: 90,000 kg (200,000 lb)

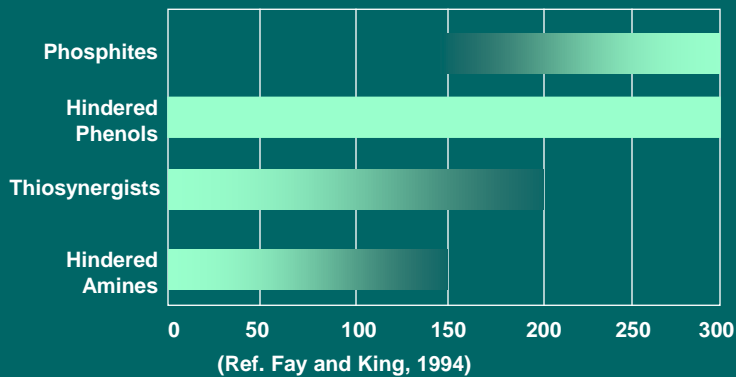


High Pressure (Left) and Standard (Right) Cells for Measuring OIT





## On choice of Std. or HP-OIT



- Std-OIT misrepresents AO packages with thiosynergists and/or hindered amines
- HP-OIT is always applicable (but \$10,000 cell and longer test time)

## 11. Oven Aging

- assessment of thermal stability of antioxidants (AOs)
- follows ASTM D5721
- forced air oven at 85°C
- Std.-OIT  $\geq$  35% ret. after 90 days exposure
- HP-OIT  $\geq$  60% ret. after 90 days
- frequency is per formulation



## 12. Ultraviolet Resistance

- assessment of UV stability of the AOs and CB (there should be synergy)
- 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  $\geq$  35% ret. after 1600 hrs.
- frequency is per formulation



## Regarding the Warranty

- manufacturers requested so as to avoid 20-year warranties and foolish expenses
- based on GRI Report #16, i.e., if AOs are present lifetime  $\approx$  200 yrs.
- GM13 was crafted to be sure the AOs are present and of proper type, i.e., OIT and oven aging verification
- also, for geomembrane used in exposed conditions a UV exposure is included
- recommended material warranty using GM17 spec is for 5-years (it promises to be 100's)
- GM17 is silent on any type of installation warranty (this is the major concern)

## Concluding Comments

- specification was essential due to NSF dropping its Std. 54 in 1997
- mfgrs. want spec for both covered and exposed GM installations
- this is MQC specification i.e., the manufacturers required tests, minimum values and frequencies
- if MQA project specific spec is more restrictive, manufacturer may ask for additional compensation

# The Basic Tables Follow

LLDPE – Smooth (SI Units)

LLDPE – Smooth (English)

LLDPE – Textured (SI Units)

LLDPE – Textured (English)

Note: The most recent version of this specification (text and tables) is available on the GSI Web Site <geosynthetic-institute.org>.

English Units

**Table 1(a) – Linear Low Density Polyethylene (LLDPE) Geomembrane (SMOOTH)**

Property	Test Method	Test Value								Testing Frequency (minimum)
		20 mils	30 mils	40 mils	50 mils	60 mils	80 mils	100 mils	120 mils	
Thickness – mils (min. ave.)	D 6189	none	none	none	none	none	none	none	none	per lot
• Lowest individual of 10 values		-10%	-10%	-10%	-10%	-10%	-10%	-10%	-10%	
Density (g/cc) (min.)	D 1535 (V1) (a)	0.919	0.918	0.916	0.915	0.913	0.912	0.910	0.910	50,000 ft <sup>2</sup>
Tensile Properties (1) (min. ave.)	D 6691									50,000 ft <sup>2</sup>
• Tensile strength – lbf/in.	Type IV	76	114	152	190	228	304	380	456	
• Break elongation – %		600	800	800	800	800	800	800	800	
% Molecular Weight (min.)	D 3511	1500	1800	2400	3000	3600	4800	6000	7200	per formulation
Tear Resistance – lb (min. ave.)	D 1004	11	18	22	27	33	44	55	66	45,000 ft <sup>2</sup>
Puncture Resistance – lb (min. ave.)	D 4813	28	42	56	70	84	112	140	168	45,000 ft <sup>2</sup>
Anti-Systemic Block Resistance Stress – % (min.)	D 5617	30	30	30	30	30	30	30	30	per formulation
Carbon Black Content – %	D 4218 (2)	2.0-3.0	2.5-3.0	2.0-3.0	2.0-3.0	2.0-3.0	2.0-3.0	2.0-3.0	2.0-3.0	45,000 ft <sup>2</sup>
Carbon Black Dispersion	D 5596	note (1)	note (1)	note (1)	note (1)	note (1)	note (1)	note (1)	note (1)	45,000 ft <sup>2</sup>
Oxidative Induction Time (OIT) (a)										
(a) Standard OIT (min. ave.)	D 3893	100	100	100	100	100	100	100	100	200,000 ft <sup>2</sup>
– at –										
(b) High Pressure OIT (min. ave.)	D 5885	400	400	400	400	400	400	400	400	
Ozone Aging at 25°C (3)	D 4721									
(a) Standard OIT (min. ave.) – % retained after 90 days	D 3893	33	33	33	33	33	33	33	33	per formulation
– at –										
(b) High Pressure OIT (min. ave.) – % retained after 90 days	D 5885	60	60	60	60	60	60	60	60	
UV Resistance (b)	D 7218									
(a) Standard OIT (min. ave.)	D 3893	34 R, (7)	34 R, (7)	34 R, (7)	34 R, (7)	34 R, (7)	34 R, (7)	34 R, (7)	34 R, (7)	per formulation
– at –										
(b) High Pressure OIT (min. ave.) – % retained after 1600 hrs (2)	D 5885	35	35	35	35	35	35	35	35	

(1) Machine direction (MD) and cross machine direction (CMD) average values should be on the basis of 5 test specimens each direction.  
 • Break elongation is calculated using a gage length of 2.0 in. at 2.0 in. min.  
 (2) Other methods such as D 1960 (tube flexure) or D 6370 (TGA) are acceptable if an appropriate correlation to D 4218 (particle flexure) can be established.  
 (3) Carbon black dispersion (only non-spherical agglomerates) for 10 different sizes.  
 • 9 in Categories 1 or 2 and 1 in Category 3.  
 (4) The manufacturer has the option to select either one of the OIT methods listed to evaluate the antioxidant content in the geomembrane.  
 (5) It is also recommended to evaluate samples at 30 and 60 days to compare with the 90-day response.  
 (6) The conditions of the test should be 20 hr. UV cycle at 75°C, followed by 4 hr. condensation at 60°C.  
 (7) Not recommended since the high temperatures of the Std-OIT test produce an accelerated result for some of the antioxidants in the UV exposed samples.  
 (8) UV resistance is based on percent retained value regardless of the original Std-OIT value.

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Table 1(b) – Linear Low Density Polyethylene (LLDPE) Geomembrane (SMOOTH)

Property	Test Method	Test Value										Testing Frequency (minimum)
		0.75 mm area (%)	0.75 mm area (%)	1.0 mm area (%)	1.25 mm area (%)	1.50 mm area (%)	2.00 mm area (%)	2.5 mm area (%)	3.0 mm area (%)	3.6 mm area (%)	4.5 mm area (%)	
Thickness (mm (nom. area))	D 5199											per roll
• lower indicated for 0.75 mm												
Density (g/m <sup>3</sup> (nom. area))	D 1505/D 792	0.918	0.918	0.918	0.918	0.918	0.918	0.918	0.918	0.918	0.918	90,000 kg
• lower indicated for any of the 10 values												9,000 kg
Tensile Properties (N (nom. area))	D 6681											
• break strength – 5% strain	Type IV	13	20	27	33	40	51	66	80			
• break elongation – %		800	800	800	800	800	800	800	800			
7% Modulus – 10 mm (nom. area)	D 5123	216	270	436	350	436	840	1055	1360			per foundation
Tear Resistance – E (nom. area)	D 1504	30	78	106	120	136	200	250	300			20,000 kg
Reaction Resistance – 10 (nom. area)	D 4813	128	190	256	310	376	500	620	750			20,000 kg
As-Synthesized Break Resistance Stress – % (nom. area)	D 5817	33	33	33	33	33	33	33	33			per foundation
Carbon Black Content – %	D 4718 (2)	2.0-3.0	2.0-3.0	2.0-3.0	2.0-3.0	2.0-3.0	2.0-3.0	2.0-3.0	2.0-3.0			20,000 kg
Carbon Black Dispersion	D 1396	none (2)	none (2)	none (2)	none (2)	none (2)	none (2)	none (2)	none (2)			20,000 kg
Oxidative Induction Time (OIT) (h)												
(a) Standard OIT (nom. area)	D 3881	100	100	100	100	100	100	100	100			90,000 kg
– at –												
(b) High Pressure OIT (nom. area)	D 3881	400	400	400	400	400	400	400	400			
Ovens Aging at 60°C (2)	D 5721											
(a) Standard OIT (nom. area) – % retained after 90 days	D 3881	35	35	35	35	35	35	35	35			per foundation
– at –												
(b) High Pressure OIT (nom. area) – % retained after 90 days	D 3881	60	60	60	60	60	60	60	60			
UV Resistance (3)	D 7138											
(a) Standard OIT (nom. area)	D 3881	N.R. (7)	N.R. (7)	N.R. (7)	N.R. (7)	N.R. (7)	N.R. (7)	N.R. (7)	N.R. (7)			per foundation
– at –												
(b) High Pressure OIT (nom. area) – % retained after 1600 hrs (8)	D 3881	35	35	35	35	35	35	35	35			

- (1) Machine direction (MD) and cross machine direction (CMD) average values should be on the basis of 3 test specimens each direction.
  - Break elongation is calculated using a gage length of 50 mm at 50 mm/min.
- (2) Other methods such as D 1801 (tube furnace) or D 6170 (TGA) are acceptable if an appropriate correlation to D 4718 (tube furnace) can be established.
- (3) Carbon black dispersion (tube size spherical agglomerates) for 10 different sizes:
  - 0 in Categories 1 or 2 and 1 in Category 3
- (4) The manufacturer has the option to select either one of the OIT methods listed to evaluate the antioxidant content in the geomembrane.
- (5) It is also recommended to evaluate samples at 10 and 60 days to compare with the 90 day response.
- (6) The condition of the test should be 23 hr UV cycle at 75°C, followed by 4 hr. continuous run at 60°C.
- (7) Not recommended since the high temperature of the Std-OIT test produces an unrealistic result for some of the antioxidants in the UV exposed samples.
- (8) UV resistance is based on percent retained value regardless of the original HP-OIT value.

Table 2(a) – Linear Low Density Polyethylene (LLDPE) Geomembrane (TEXTURED)

Property	Test Method	Test Value										Testing Frequency (minimum)
		20 mils area (%)	30 mils area (%)	40 mils area (%)	50 mils area (%)	60 mils area (%)	80 mils area (%)	100 mils area (%)	120 mils area (%)	150 mils area (%)	180 mils area (%)	
Thickness (mils (nom. area))	D 5994											per roll
• lower indicated for 0 out of 10 values												
• lower indicated for any of the 10 values												
Aspect Ratio (mils (nom. area) (2))	D 1460	11	11	11	11	11	11	11	11	11	11	3000' x 60' (2)
Density (g/m <sup>3</sup> (nom. area))	D 1505/D 792	0.918	0.918	0.918	0.918	0.918	0.918	0.918	0.918	0.918	0.918	200,000 lb
• lower indicated for any of the 10 values												20,000 lb
Tensile Properties (N (nom. area))	D 6681											
• break strength – 5% strain	Type IV	10	45	68	73	80	110	118	168			
• break elongation – %		250	250	250	250	250	250	250	250			
7% Modulus – 6 in (nom. area)	D 5123	1300	1800	2400	2000	2600	4800	6000	7500			per foundation
Tear Resistance – E (nom. area)	D 1504	11	28	32	33	33	46	51	60			45,000 lb
Reaction Resistance – 10 (nom. area)	D 4813	22	44	44	55	66	88	110	132			45,000 lb
As-Synthesized Break Resistance Stress – % (nom. area)	D 5817	30	30	30	30	30	30	30	30			per foundation
Carbon Black Content – %	D 4718 (4)	2.0-3.0	2.0-3.0	2.0-3.0	2.0-3.0	2.0-3.0	2.0-3.0	2.0-3.0	2.0-3.0			45,000 lb
Carbon Black Dispersion	D 1396	none (2)	none (2)	none (2)	none (2)	none (2)	none (2)	none (2)	none (2)			45,000 lb
Oxidative Induction Time (OIT) (h)												
(a) Standard OIT (nom. area)	D 3881	300	300	300	300	300	300	300	300			200,000 lb
– at –												
(b) High Pressure OIT (nom. area)	D 3881	400	400	400	400	400	400	400	400			
Ovens Aging at 60°C (2)	D 5721											
(a) Standard OIT (nom. area) – % retained after 90 days	D 3881	35	35	35	35	35	35	35	35			per foundation
– at –												
(b) High Pressure OIT (nom. area) – % retained after 90 days	D 3881	60	60	60	60	60	60	60	60			
UV Resistance (3)	D 7138											
(a) Standard OIT (nom. area)	D 3881	N.R. (8)	N.R. (8)	N.R. (8)	N.R. (8)	N.R. (8)	N.R. (8)	N.R. (8)	N.R. (8)			per foundation
– at –												
(b) High Pressure OIT (nom. area) – % retained after 1600 hrs (8)	D 3881	35	35	35	35	35	35	35	35			

- (1) OIT (h) readings: 1 out of 10 runs to be 2.0 min, and lower individual reading must be 2.0 min; also see Table 9.
- (2) Advise the manufacturer rate for double sided oriented cover.
- (3) Machine direction (MD) and cross machine direction (CMD) average values should be on the basis of 3 test specimens each direction.
  - Break elongation is calculated using a gage length of 2.0 in. at 2.0 in./min.
- (4) Other methods such as D 1801 (tube furnace) or D 6170 (TGA) are acceptable if an appropriate correlation to D 4718 (tube furnace) can be established.
- (5) Carbon black dispersion (tube size spherical agglomerates) for 10 different sizes:
  - 0 in Categories 1 or 2 and 1 in Category 3
- (6) The manufacturer has the option to select either one of the OIT methods listed to evaluate the antioxidant content in the geomembrane.
- (7) It is also recommended to evaluate samples at 10 and 60 days to compare with the 90 day response.
- (8) The condition of the test should be 30 hr UV cycle at 75°C, followed by 4 hr. continuous run at 60°C.
- (9) Not recommended since the high temperature of the Std-OIT test produces an unrealistic result for some of the antioxidants in the UV exposed samples.
- (10) UV resistance is based on percent retained value regardless of the original HP-OIT value.

**Table 2(b) – Linear Low Density Polyethylene (LLDPE) Geomembrane  
(TEXTURED)**

Property	Test Method	Test Value								Testing Frequency (minimum)	
		0.75 mm	0.75 mm	1.0 mm	1.25 mm	1.50 mm	1.75 mm	2.00 mm	2.25 mm		2.5 mm
Thickness min (mm, in.)	D 5994	min. (-1%)	min. (-1%)	min. (-1%)	min. (-1%)	min. (-1%)	min. (-1%)	min. (-1%)	min. (-1%)	min. (-1%)	per roll
• lowest individual for 5 out of 10 values		-10%	-10%	-10%	-10%	-10%	-10%	-10%	-10%	-10%	
• lowest individual for any of the 10 values		-10%	-10%	-10%	-10%	-10%	-10%	-10%	-10%	-10%	
Aspect Ratio (min. mm, in.) <sup>(1)</sup>	D 5486	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	Every 2 <sup>nd</sup> roll (2)
Density g/cc (mm.)	D 1505, D 500	0.939	0.939	0.939	0.939	0.939	0.939	0.939	0.939	0.939	96,000 kg 9,000 kg
Tensile Properties (3) (mm, in.)	D 4503										
• break strength – 10 min	Type IV	0	0	11	13	18	21	26	31	31	
• break elongation – %		210	250	200	240	220	210	210	210	210	
% Modulus – 10 min (mm.)	D 5113	210	216	435	520	630	840	1010	1200	1300	per
Tear Resistance – 10 (mm, in.)	D 1094	50	50	100	110	130	150	200	210	200	Resistant
Puncture Resistance – 10 (mm, in.)	D 4633	100	110	200	230	300	400	500	600	600	20,000 kg
Anti-Osmosis: Break Resistance Stress – % (mm.)	D 5617	30	30	30	30	30	30	30	30	30	per
Carbon Black Content – %	D 4218 (4)	2.0-3.0	2.0-3.0	2.0-3.0	2.0-3.0	2.0-3.0	2.0-3.0	2.0-3.0	2.0-3.0	2.0-3.0	Resistant
Carbon Black Dispersion	D 5198	none (5)	none (5)	none (5)	none (5)	none (5)	none (5)	none (5)	none (5)	none (5)	20,000 kg
Oxidative Induction Time (OIT) (6)											96,000 kg
(a) Standard OIT (mm, in.)	D 5881	100	100	100	100	100	100	100	100	100	
(b) High Pressure OIT (mm, in.)	D 5881	400	400	400	400	400	400	400	400	400	
Open Aging at 80°C (7)	D 5721										
(a) Standard OIT (mm, in.) – % retained after 90 days	D 5881	21	21	21	21	21	21	21	21	21	per
(b) High Pressure OIT (mm, in.) – % retained after 90 days	D 5881	60	60	60	60	60	60	60	60	60	Resistant
UV Resistance (8)											
(a) Standard OIT (mm, in.)	D 5881	11 R, (6)	12 R, (6)	12 R, (6)	12 R, (6)	12 R, (6)	12 R, (6)	12 R, (6)	12 R, (6)	12 R, (6)	per
(b) High Pressure OIT (mm, in.) – % retained after 1000 hrs (10)	D 5881	21	21	21	21	21	21	21	21	21	Resistant

(1) Of 10 readings, 5 out of 10 must be  $\leq$  0.15 mm, and lower individual reading must be  $\leq$  0.15 mm, also see Item 8  
 (2) Alternate the measurement side for double sided textured slabs  
 (3) Machine direction (MD) and cross machine direction (CMD); average values should be on the basis of 5 test specimens each direction  
 • Break elongation is calculated using a gage length of 10 mm or 10 mm/min  
 (4) Other methods such as D 3961 (Tear Resistance) or D 6579 (TGA) are acceptable if an appropriate correlation to D 4218 (carbon black content) can be established  
 (5) Carbon black dispersion (only seen upon aggregation) for 10 different values  
 • 0 in Categories 1, 2, 3 and 4 in Category 3  
 (6) The manufacturer has the option to select either one of the OIT methods listed to evaluate the antioxidant content in the geomembrane  
 (7) It is also recommended to evaluate samples at 30 and 60 days to compare with the 90-day exposure  
 (8) The condition of the test should be 20 hr UV cycle at 70°C followed by 4 hr condensation at 80°C  
 (9) Not recommended since the high temperature of the UV-CIT test produces no correlation to the UV exposed samples  
 (10) UV resistance is based on percent retained value regardless of the original MD-OIT value