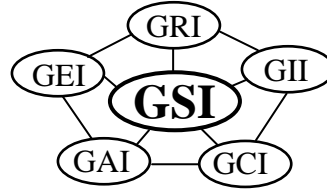


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Revision 8: September 10, 2015
Revision Schedule on pg. 12

GRI Test Method GM18**

Standard Specification for

“Test Methods, Test Properties and Testing Frequencies for Flexible Polypropylene (fPP and fPP-R) Nonreinforced and Reinforced Geomembranes”

This specification was developed by the Geosynthetic Research Institute (GRI), with the cooperation of the member organizations for general use by the public. It is completely optional in this regard and can be superseded by other existing or new specifications on the subject matter in whole or in part. Neither GRI, the Geosynthetic Institute, nor any of its related institutes, warrant or indemnifies any materials produced according to this specification either at this time or in the future.

1. Scope

- 1.1 This specification covers flexible polypropylene geomembranes which are nonreinforced (fPP) in thicknesses of 30 mils (0.75 mm), 40 mils (1.02 mm), 60 mils (1.52 mm) and also scrim reinforced (f PP-R) in thicknesses of 36 mils (0.91 mm) and 45 mils (1.14 mm) and 60 mils (1.52 mm).
- 1.2 This specification sets forth a set of physical, mechanical and endurance properties that must be met or exceeded by the geomembrane being manufactured.
- 1.3 In the context of quality systems and management, this specification represents manufacturing quality control (MQC).

Note 1: Manufacturing quality control represents those actions taken by a manufacturer to ensure that the product represents the stated objective and properties set forth in this specification.

- 1.4 This standard specification is intended to ensure good quality and performance of fPP and fPP-R geomembranes in general applications, but may not be adequate for

*This Registered GRI standard is developed by the Geosynthetic Research Institute through consultation and review by the member organizations. This specification will be reviewed at least every two-years, or on an as-required basis. In this regard it is subject to change at any time. The most recent revision date is the effective version.

the complete specification of a specific situation. Additional tests, or more restrictive values for the tests indicated, may be necessary under conditions of a particular application.

- 1.5 This specification does not cover installation considerations which are independent of the manufacturing of the geomembrane.

Note 2: For information on installation techniques, users of this standard are referred to the geosynthetics literature, which is abundant on the subject.

2. Referenced Documents

2.1 ASTM Standards

- D 751 Test Methods for Coated Fabrics
- D 1004 Test Method for Tear Resistance (Graves Tear) of Plastic Film and Sheeting
- D 1603 Test Method for Carbon Black in Olefin Plastics
- D 2136 Test Method for Coated Fabrics – Low Temperature Bend Test
- D 4218 Test Method for Determination of Carbon Black Content in Polyethylene Compounds by the Muffle-Furnace Technique
- D 4439 Standard Terminology for Geosynthetics
- D 4833 Test Method for Index Puncture Resistance of Geotextiles, Geomembranes and Related Products
- D 4873 Guide for Identification, Storage and Handling of Geosynthetics
- D 5199 Test Method for Measuring Nominal Thickness of Geotextiles and Geomembranes
- D 5261 Test Method for Measuring Mass per Unit Area of Geotextiles
- D 5323 Practice for Determination of 2% Secant Modulus for Polyethylene Geomembranes
- D 5538 Standard Practice for Thermoplastic Elastomers – Terminology and Abbreviations
- D 5617 Test Method for Multi-Axial Tensile Test for Geosynthetics
- D 5884 Test Method for Determining the Tearing Strength of Internally Reinforced Geomembranes
- D 6636 Determination of Ply Adhesion Strength of Reinforced Geomembranes
- D 6693 Test Method for Determining Tensile Properties of Nonreinforced Polyethylene and Nonreinforced Flexible Polypropylene Geomembranes
- D 7004 Test Method for Garb Tensile Properties of Reinforced Geomembranes
- D 7238 Test Method for Effect of Exposure of Unreinforced Polyolefin Geomembrane Using Fluorescent UV Condensation Apparatus

2.2 GRI Standards

- GM 16 Test Method for Observation of Surface Cracking of Geomembranes

GM 23 Test Method for Observation of Surface Chalking of Geomembranes
(draft)

2.3 Other References

U. S. Environmental Protection Agency Technical Guidance Document "Quality Control Assurance and Quality Control for Waste Containment Facilities," EPA/600/R-93/182, September 1993, 305 pgs.

Koerner, R. M., Hsuan, Y. G. and Koerner, G. R. (2008), "Freshwater and Geosynthetics: A Perfect Marriage," Proc. 1st Pan American Geosynthetics Conference, March 2-5, 2008, Cancun, Mexico, IFAI Publisher, Roseville, MN (on CD).

3. Definitions

Manufacturing Quality Control (MQC) - A planned system of inspections that is used to directly monitor and control the manufacture of a material which is factory originated. MQC is normally performed by the manufacturer of geosynthetic materials and is necessary to ensure minimum (or maximum) specified values in the manufactured product. MQC refers to measures taken by the manufacturer to determine compliance with the requirements for materials and workmanship as stated in certification documents and contract specifications.

ref. EPA/600/R-93/182

Manufacturing Quality Assurance (MQA) - A planned system of activities that provides assurance that the materials were constructed as specified in the certification documents and contract specifications. MQA includes manufacturing facility inspections, verifications, audits and evaluation of the raw materials (resins and additives) and geosynthetic products to assess the quality of the manufactured materials. MQA refers to measures taken by the MQA organization to determine if the manufacturer is in compliance with the product certification and contract specifications for the project.

ref. EPA/600/R-93/182

Formulation, n - The mixture of a specific combination of ingredients identified by type, properties and quantity. For flexible polypropylene geomembranes a formulation is defined as the exact percentages and types of resin(s), additives, and carbon black or colorants.

Note 3: The geomembrane focused upon in this standard specification shall be formulated from virgin flexible polypropylene, in amounts greater than 85% by weight of the total polymer content. The remaining 15% shall be comprised of compatible polymers and/or pigments, stabilizers, and colorants that are suitably compounded to satisfy the physical, mechanical and endurance requirements in the specification; see ASTM Practice D 5538 for definitions. The

formulations shall not contain fillers (such as talc or calcium carbonate) postconsumer (PCR) plastics, or any other ingredients that could interfere with the long-term durability of the geomembrane. No more than 10% rework resin is allowed for the production of the geomembrane and, if used, it shall be fully compatible with the parent material.

Flexible Polypropylene, n. [per ASTM D4439] – a material having a 2% secant modulus of less than 300 MPa (40,000 lb/in.²) as determined by ASTM D5323 produced by polymerization of propylene with or without other alpha olefin monomers.

Rework, n - Polymer which has been converted into a geosynthetic material and then ground into chips for reintroduction into the extruder without leaving the plant, e.g., edge trim, out-of-spec thickness material, etc.

Chalking, n. – Formation of powdery deposit on the surface of a coating that has been exposed to some form of degradation. It is commonly found on coatings that have been exposed outdoors to sun and rain. The powder is in fact the pigment and extender that remains after the binder has been destroyed by weathering. (BS 3900-H6: ISO 4628/6)

Note 4: In addition to the coatings referred to above, chalking is also found in geomembranes when exposed outdoors and in geomembranes when incubated in laboratory weatherometers.

Minimum Average, n. - Many index test methods, such as thickness, mass, puncture, tear, etc., require a number of test readings to be taken across an individual roll or panel immediately after it is manufactured and then averaged accordingly. The particular standard calls out this practice in detail. For a full field project, however, many rolls or panels are required and the minimum average is the minimum of all the specific average values of the individual rolls or panels. In this regard, “minimum average” is invariably lower than the “average of the average” values which has sometimes been reported in the past.

4. Material Classification and Formulation

4.1 This specification covers flexible polypropylene geomembranes which are nonreinforced (fPP) and scrim reinforced, hence the designation fPP-R.

4.2 The flexible polypropylene resin from which the geomembrane is made shall conform to the definition presented in Section 3.

4.3 The flexible polypropylene resin shall be virgin material with no more than 10% rework. If rework is used, it must be an approved formulation similar to the parent material.

4.4 No post consumer resin (PCR) of any type shall be added to the formulation.

- 4.5 For reinforced flexible polypropylene, the fabric reinforcement (also called the “scrim”) shall be present so as to give the desired specification values to be presented in the next section.

Note 5: Fabric scrims are sometimes 1000 denier in either a 9×9 weft-inserted or a 10×10 basket pattern (i.e., 9 or 10 yarns per inch of width in both machine and cross-machine directions). They are usually made from high tenacity polyester resin. Other patterns and polymers are also possible. Reinforced geomembranes are sometimes referred to as “supported” geomembranes.

5. Physical, Mechanical and Endurance Property Requirements

- 5.1 The geomembrane shall conform to the test property requirements prescribed in Tables 1(a) and 1(b). Table 1(a) is in U. S. Standard units and Table 1(b) is in SI (metric) units. The conversion from U. S. Standard to SI (metric) units is soft. It is to be understood that the table refers to the latest revision of the referenced test methods and practices.

Note 6: The tensile strength properties of unreinforced fPP geomembranes in this specification were originally based on ASTM D 638 which uses a laboratory testing temperature of $23^{\circ}\text{C} \pm 2^{\circ}\text{C}$. Since ASTM Committee D35 on Geosynthetics adopted ASTM D 6693 (in place of D 638), this GRI Specification follows accordingly. The difference is that D 6693 uses a testing temperature of $21^{\circ}\text{C} \pm 2^{\circ}\text{C}$. The numeric values of strength and elongation were not changed in this specification. If a dispute arises in this regard, the original temperature of $23^{\circ}\text{C} \pm 2^{\circ}\text{C}$ should be utilized for testing purposes.

Note 7: There are several tests that could have been included in this specification which are omitted because it is felt that they are outdated, irrelevant, or generate information that is not necessary to evaluate on a routine MQC basis. The following tests have been purposely omitted:

- Volatile Loss
- Dimensional Stability
- Coeff. of Linear Expansion
- Resistance to Soil Burial
- Low Temperature Impact
- Wide Width Tensile
- Water Vapor Transmission
- Carbon Black Dispersion
- Oxidative Induction Time (Standard and High Pressure)
- Water Absorption
- Ozone Resistance
- Modulus of Elasticity
- Hydrostatic Resistance
- Tensile Impact
- Field Seam Strength
- Mullen Burst
- Various Toxicity Tests

Note 8: There are several tests which are included in this standard because they are relevant and important in the context of current manufacturing processes. The following incubation methods and subsequent test methods have been purposely added:

- Ultraviolet Resistance by UV Fluorescent Method
- Multi-Axial Burst

Note 9: There are other tests in this standard, focused on a particular property, which are updated to current standards. The following are in this category:

- Tensile Strength Properties
- Mass per Unit Area
- Thickness
- Tear Resistance
- Puncture Resistance
- Ply Adhesion

Note 10: There are several GRI tests currently included in this standard. Since these topics are not covered in ASTM standards, this is necessary. They are the following:

- Surface Cracking
- Surface Chalking

5.2 Details of the endurance-related procedure, i.e., the UV Fluorescent Method per ASTM D7238 (mod. to 70°C) incubation procedure, are as follows:

This simulated weathering exposure device uses UV fluorescent tubes at 0.78 (W/(m²·nm)) with 340 nm wavelength bulbs (UVA-340) and measures the change in properties of the removed test specimens. The cycle cam is set to provide 24 hour cycles as follows: 20 hours UV cycle at 70°C followed by 4 hour condensation at 60°C. This procedure requires an initial and unexposed determination of the as-received properties, i.e., before incubation. The nonreinforced specimens are evaluated for their retained strength and elongation behavior. The reinforced specimens are evaluated for their cracking and chalking behavior.

Note 11: Earlier versions of this specification had the endurance criteria (oven aging and UV weathering) based on reduction of oxidative inductive time (OIT) from the as-received value. This was subsequently found to be not fully reliable so this reinstated specification is now based completely on UV weathering using the fluorescent tube method (ASTM D 7238). The 20,000 light hour exposure time is admittedly long, however, is felt to be in keeping

with both nonexposed and exposed applications of fPP and fPP-R geomembranes.

Note 12: At an irradiance level of $0.78 \text{ W}/(\text{m}^2 \cdot \text{nm})$ and at 340 nm wavelength, the radiant exposure (RE) of a successful geomembrane passing 20,000 light hours is as follows:

$$\begin{aligned} \text{RE} &= 0.78 \times 20,000 (60 \times 60) \times (1/1000) \\ &= 56,160 \text{ kJ}/(\text{m}^2 \cdot \text{nm}) \text{ at } 340 \text{ nm} \end{aligned}$$

Note 13: Earlier versions of this specification had the endurance criteria based on black versus other colors. This version does not distinguish on the basis of color and all colors must meet the criteria given.

5.3 As noted in the adoption and revision schedule included on Page 10, this specification was suspended in 2004 and then withdrawn in 2007. During this time and up to its reinstatement in 2009 considerable research on the durability criterion has been undertaken by the institute. This effort resulted in the 20,000 light hour requirement per ASTM D7238 at 70°C; see Koerner, et al. (2008). Related research activities are given in the following notes:

Note 14: There have been field reports that imposed tensile stresses have caused premature failures in both fPP and fPP-R geomembranes. At the institute we have evaluated two types of such stresses (wide width and over rollers) and not found issues in products that passed 20,000 light hours of incubation. That said, further research might still be considered.

Note 15: There have been field reports that abrupt corners in the products during factory folding have caused premature failures in both fPP and fPP-R geomembranes. At the institute we have evaluated 90°, 180°, and corner (or dead) folds in numerous aggressive solutions at 50°C for 1000 hours and not found issues in products that passed 20,000 light hours of incubation. That said, further research might still be considered.

Note 16: There have been field reports that chlorine and chloride compounds (even in minute quantities) have caused premature failures in both fPP and fPP-R geomembranes. At the institute we have evaluated a number of chemical solutions (tap water, 1% sulfuric acid, 10 M calcium chloride, 10% Igepal, 10 M lime 10% hydrogen peroxide and 10% bleach solution) at 50°C for 1000 hours and not found issues in products that passed 20,000 light hours of incubation. That said, further research might still be considered.

- 5.4 The various properties of the fPP and fPP-R geomembranes shall be tested at the minimum frequencies shown in Table 1. If the specific manufacturer's quality control guide is more stringent and is certified accordingly, it must be followed in like manner.

Note 17: This specification is focused on manufacturing quality control (MQC). Conformance testing and manufacturing quality assurance (MQA) testing are at the discretion of the purchaser and/or quality assurance engineer, respectively.

6. Workmanship and Appearance

- 6.1 Smooth fPP geomembrane shall have good and uniform appearance qualities. It shall be free from such defects that would affect the specified properties of the geomembrane.
- 6.2 Scrim reinforced fPP-R geomembrane shall generally have a uniform undulating appearance. It shall be free from irregular yarns, yarns that are bunched together, yarns crossing over one another, and such defects that would affect the specified properties of the geomembrane.
- 6.3 For fPP-R geomembranes there is to be no exposed scrim except for roll ends. A 0.375 ± 0.25 in. (10 ± 6 mm) edge encapsulation on each side is required.
- 6.4 General manufacturing procedures shall be performed in accordance with the manufacturer's internal quality control guide and/or documents.

7. MQC Sampling

- 7.1 Sampling shall be in accordance with the specific test methods listed in Table 1. If no sampling protocol is stipulated in the particular test method, then test specimens shall be taken evenly spaced across the entire roll width.
- 7.2 The number of tests shall be in accordance with the appropriate test methods listed in Table 1.
- 7.3 The average of the test results should be calculated per the particular standard cited and compared to the minimum value listed in these tables. For the entire lot, or complete field project, of rolls or panels the values listed are the minimum average values and are designated as "min. ave." (See Section 3 for definition)

8. MQC Retest and Rejection

- 8.1 If the results of any test do not conform to the requirements of this specification, retesting to determine acceptance or rejection should be done in accordance with the manufacturing protocol as set forth in the manufacturer's quality manual.

9. Packaging and Marking

- 9.1 The geomembrane shall be rolled onto a substantial core or core segments and held firm by dedicated straps/slings, or other suitable means. The rolls must be adequate for safe transportation to the point of delivery, unless otherwise specified in the contract or order.
- 9.2 The geomembrane can also be folded in an accordion manner and placed on a wooden pallet. The entire package is to be protected by a cardboard enclosure and the entire assembly banded together with plastic strapping.
- 9.3 Identify the product per ASTM D4873, which also includes information on storage and handling.

Note 18: It is considered to be good practice to archive samples of the final geomembrane. At the least, the manufacturer and owner should retain samples along with the “cut sheets” of original physical, mechanical, and endurance testing values. The samples should be stored in a sealed zip-locked polyethylene bag and properly labeled and dated.

10. Certification

- 10.1 Upon request of the purchaser in the contract or order, a manufacturer's certification that the material was manufactured and tested in accordance with this specification, together with a report of the test results, shall be furnished at the time of shipment.

Note 19: The authentication and certification of the test methods, procedures, and resulting values of any or all properties in Table 1 should be communicated between the parties involved. This can be between any, or all, of the following; manufacturer, specifier, purchaser, owner, and/or regulator.

Note 20: The authentication that the precise formulation of the material shipped to the job site is the same as that originally tested should be communicated between the parties involved. By precise formulation is meant the type and amount of resin(s), as well as the types and amounts of all additives; recall Note 3.

U. S. Standard Units

Table 1(a) – Flexible Polypropylene Nonreinforced (fPP) and Reinforced (fPP-R) Geomembranes

Property	Test Method ASTM or GRI	fPP 30 mils	fPP 40 mils	fPP 60 mil	fPP-R 36 mils	fPP-R 45 mils	fPP-R 60 mil	Testing Frequency (minimum)
Mass per Unit Area – lb/ft ² (min. ave.)	D5261	0.12	0.16	0.20	0.15	0.18	0.24	15,000 lb
Thickness	D5199							per roll
• Nominal (mils)		30	40	60	36	45	60	
• min. ave. (mils)		27	36	54	32	40	54	
Tensile Strength								
• dumbbell ⁽¹⁾ – lb/in. (min. ave.)	D6693-IV	60	72	96	-	-	-	15,000 lb
• grab ⁽¹⁾ – lb (min. ave.)	D7004	-	-	-	200	250	300	15,000 lb
Tensile Elongation								
• dumbbell ^(1,2) - % (min. ave.)	D6693-IV	700	700	700	-	-	-	15,000 lb
• grab ⁽¹⁾ - % (min. ave.)	D7004	-	-	-	22	22	22	15,000 lb
Multiaxial Elongation - %	D5617	120	120	120	-	-	-	formulation
Tear Resistance								
• nonreinforced ⁽¹⁾ – lb (min. ave.)	D1004	10	12	18	-	-	-	15,000 lb
• reinforced ⁽¹⁾ – lb (min. ave.)	D5884	-	-	-	55	55	55	15,000 lb
Puncture Resistance – lb (min. ave.)	D4833	25	30	40	75	85	100	15,000 lb
Ply Adhesion – lb/in. (min. ave.)	D6636	-	-	-	15	15	15	15,000 lb
Low Temperature Flexibility - °F	D2136 ⁽³⁾	-40	-40	-40	-40	-40	-40	formulation
Carbon Black Content ⁽⁴⁾ - %	D4218	2-15	2-15	2-15	2-15	2-15	2-15	45,000 lb
Ultraviolet Light Resistance ^(5,6)	D7238 @ 70°C							per formulation
(a) % strength retained after 20,000 light hrs. - or -	D6693-IV	≥ 50			≥ 50			
(b) % elongation retained after 20,000 light hrs. - and -	D6693-IV	≥ 50			≥ 50			
(c) Surface Cracking Observation after 20,000 light hrs. (d) Surface Chalking (or Powdering) after 20,000 light hrs.	GM16 GM23	none minor			none minor			

(1) Test methods modified to 20 in./min. for unreinforced and 12 in./min. for reinforced

(2) Calculation based on a 2.0 in. gage length

(3) Using 1/8 in. mandrel for 4-hours.

(4) Applicable only to black geomembranes. Also D1603 is an acceptable method to determine carbon black content.

(5) The conditions of the UV Fluorescent exposure method should be 20 hr. UV cycle at 70°C followed by 4 hr. condensation at 60°C.

(6) See Section 5.2 for fPP-R geomembranes.

SI (METRIC) UNITS

Table 1(b) – Flexible Polypropylene Nonreinforced (fPP) and Reinforced (fPP-R) Geomembranes

Property	Test Method ASTM or GRI	fPP 0.76 mm	fPP 1.02 mm	fPP 1.52 mm	fPP-R 0.91 mm	fPP-R 1.14 mm	fPP-R 1.52 mm	Testing Frequency (minimum)
Mass per Unit Area – kg/m ² (min. ave.)	D5261	0.59	0.78	0.98	0.73	0.88	1.17	7500 kg
Thickness	D5199							per roll
• Nominal (mils)		0.76	1.02	1.52	0.91	1.14	1.52	
• min. ave. (mils)		0.68	.92	1.37	0.82	1.03	1.37	
Tensile Strength								
• dumbbell ⁽¹⁾ – kN/m (min. ave.)	D6693-IV	11	13	17	-	-	-	7500 kg
• grab ⁽¹⁾ – N (min. ave.)	D7004	-	-	-	890	1110	1340	7500 kg
Tensile Elongation								
• dumbbell ^(1,2) - % (min. ave.)	D6693-IV	700	700	700	-	-	-	7500 kg
• grab ⁽¹⁾ - % (min. ave.)	D7004	-	-	-	22	22	22	7500 kg
Multiaxial Elongation - %	D5617	120	120	120	-	-	-	formulation
Tear Resistance								
• nonreinforced ⁽¹⁾ – N (min. ave.)	D1004	45	53	80	-	-	-	7500 kg
• reinforced ⁽¹⁾ – N (min. ave.)	D5884	-	-	-	245	245	245	7500 kg
Puncture Resistance – N (min. ave.)	D4833	110	130	180	330	380	440	7500 kg
Ply Adhesion – kN/m (min. ave.)	D6636	-	-	-	2.6	2.6	2.6	7500 kg
Low Temperature Flexibility - °C	D2136 ⁽³⁾	-40	-40	-40	-40	-40	-40	formulation
Carbon Black Content ⁽⁴⁾ - %	D4218	2-15	2-15	2-15	2-15	2-15	2-15	22,000 kg
Ultraviolet Light Resistance ^(5,6)	D7238 @ 70°C							per formulation
(a) % strength retained after 20,000 light hrs. - or -	D6693-IV		≥ 50			≥ 50		
(b) % elongation retained after 20,000 light hrs. - and -	D6693-IV		≥ 50			≥ 50		
(c) Surface Cracking Observation after 20,000 light hrs. (d) Surface Chalking (or Powdering) after 20,000 light hrs.	GM16 GM23		none minor			none minor		

(1) Test methods modified to 500 mm/min. for unreinforced and 12 in./min. for reinforced

(2) Calculation based on a 50 mm gage length

(3) Using 32 mm mandrel for 4-hours.

(4) Applicable only to black geomembranes. Also D1603 is an acceptable method to determine carbon black content.

(5) The conditions of the UV Fluorescent exposure method should be 20 hr. UV cycle at 70°C followed by 4 hr. condensation at 60°C.

(6) See Section 5.2 for fPP-R geomembranes.

Adoption and Revision Schedule
for
fPP Specification per GRI-GM18

“Test Properties, Testing Frequency and Recommended Warranty for Flexible Polypropylene (fPP and fPP-R) Nonreinforced and Reinforced Geomembranes”

- Adopted: February 18, 2002
- Revision 1: June 23, 2003: Adopted ASTM D 6693, in place of ASTM D 638 for tensile strength testing. Also added Note 5.
- Revision 2: August 12, 2003: S.I. conversion errors in mass corrected
- Suspended: May 3, 2004
- Withdrawn: January 22, 2007
- Revision 3: March 20, 2009: Changed endurance criteria from OIT testing to 50% percent strength and elongation retained (for nonreinforced fPP) and no cracking or chalking (for reinforced fPP-R) after 20,000 light hours of UV-fluorescent exposure per ASTM D 7238 at 70°C. Numerous notes have been added as well as editorial corrections. Also removed recommended warranty from the specification.
- Revision 4: June 18, 2009: Corrected calculation for radiant exposure (RE).
- Revision 5: February 1, 2011: Added 60 mil (1.52 mm) fPP and fPP-R to the specification.
- Revision 6: December 17, 2012: Editorial changes.
- Revision 7: August 4, 2014: Reviewed range of C.B. Content from 2-3% to 2-15% recognizing that thermoset resins can be added up to 15% per Note 3.
- Revision 8: September 10, 2015: Changed thickness description from “lowest individual specimen” to “minimum average” in Tables 1a and 1b.