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Revision #2: 1/30/2023*
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GRI Test Method GM33

Standard Test Method for

Determination of the Strain Hardening Modulus as it relates to Stress Crack Resistance Characteristics of HDPE Geomembranes

1. Scope

1.1. This test method presents a technique for determining the strain hardening modulus of HDPE geomembranes, based on ASTM D6693 testing.

1.2. This test method can be used for testing smooth HDPE geomembrane of thickness between 0.5 and 5 millimeters (20 and 200 mils)

1.3. The test method will facilitate comparison of characteristics of similar materials by standardizing the method for deriving the onset, modulus, and break point on the stress-strain curve from an HDPE Dog Bone Tensile Test. Strain hardening data can be appropriate for assessing the stress crack susceptibility of HDPE geomembranes. However, it should be very clearly stated that this method shows good correlation between strain hardening modulus and stress crack performance within a specific formulation (resin type plus master batch). In addition, this method shows very poor correlation between strain hardening modulus and stress

*This GRI standard test method is developed by the Geosynthetic Research Institute through consultation and review by the member organizations. This method 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.

crack performance across different formulations. As such, this method is a useful manufacturing quality control (MQC) tool but is not appropriate for setting specification criteria by engineers to compare different geomembranes. To this end, if formulations are compared, they should be of the same supplier, grade, and density.

1.4. The values stated in SI units are to be regarded as the standard. The values given in imperial units (in parentheses) are for information only.

1.5. This test method does not purport to address all the safety concerns, if any, associated with its use. It is the responsibility of the user of this test method to establish appropriate safety, health, and environmental test methods and determine the applicability of regulatory limitations prior to use.

1.6. This test method was developed in accordance with internationally recognized principles on standardization established in the Decision on Principles for the Development of International Standards, Guides, and Recommendations issued by the World Trade Organization Technical Barriers to Trade (TBT) Committee.

1.7. The strain hardening modulus testing procedure specified by this test method (GM33) differs significantly from the strain hardening modulus testing procedure specified by ISO 18488. Departures include but are not limited to the following.

1.7.1. Test is performed on specimens cut from manufactured geomembranes rather than 0.3 mm compression molded coupons.

1.7.2. This test utilizes cross head movement rather than deflection data from an extensometer for elongation determinations.

2. Referenced Documents

2.1. ASTM D4439 Terminology for Geosynthetics

2.2. ASTM D5397 Test Method for Evaluation of Stress Crack Resistance of Polyolefin Geomembranes using Notched Constant Tension Load Test

2.3. ASTM D6693 Determination of Tensile Properties of Nonreinforced Polyethylene and Nonreinforced Flexible Polypropylene Geomembranes

2.4. ISO 18488: Polyethylene (PE) materials for piping systems – Determination of Strain Hardening Modulus in relation to slow crack growth – Test Method

2.5. Havermans - van Beek, D.J.M., Delieck, R., McCarthy, M., Kloth, R. and Kurelec, L. (2010). An elegant and fast method to predict the slow crack growth behavior of high-density polyethylene pipe materials. Proceedings of the Plastics Pipes XV Conference, Vancouver, Canada. pp 814-825.

2.6. Hsuan, Y. H., Lord, Jr., A. E., and Koerner, R. M. (1990), "Ductile-to-Brittle Transition Time in Polyethylene Geomembrane Sheet," Proc. Geosynthetic Testing for Waste Containment Applications, R. M. Koerner, Editor, ASTM STP 1081, West Conshohocken, PA, pp. 95-109.

2.7. Kureleca, L., M. Teeuwenb, H. Schoffeleersb, R. Deblieckb, (2005) "Strain hardening modulus as a measure of environmental stress crack resistance of high-density polyethylene", Polymer Journal Elsevier Ltd. Volume 5 number 061. Polymer 46 pp 6369-6379.

2.8. Ramsey, B., H. Zanzinger and E. Zimmel, (2018) "New technique for predictive geomembrane stress crack performance: commercial application" IGS Conference: 11th International Conference on Geosynthetics Seoul, Korea pp 210-216.

2.9. Zanzinger, H., Gerets, B., Wenzel, M., Hausmann, S. and Engelsing, K. (2015): Determination of the Stress Cracking Resistance of HDPE Geomembranes by Using Accelerated Test Methods. Geosynthetics 2015, Portland, Oregon, USA, pp 938-944.

3. Terminology

3.1. Definitions of terms applying to this test method appear in ASTM D4439.

4. Significance and Use

4.1. This test method is designed to produce strain hardening properties of HDPE geomembranes. The data obtained in this method are useful for qualitative characterization, research, and development, especially when discussing stress cracking susceptibility. It may be necessary to modify this procedure for use when testing certain materials, as recommended by the material specifications. It is advisable to refer to the material manufacturer.

4.2. Strain hardening properties may vary with specimen preparation, test speed, and environment when testing. Where precise comparative results are required, these factors must be carefully monitored and controlled. Care must be exercised to ensure that all specimens are prepared in the same way. Similarly, for the purpose of comparison, care must be taken to ensure the maximum degree of uniformity in terms of preparation, treatment, and handling.

5. Apparatus

5.1. *Testing Machine* - A testing machine of the constant rate of crosshead movement type calibrated per ASTM E4 is required, which consists of the following:
Fixed Member - A fixed or essentially stationary member carrying one grip.
Movable Member - A movable member carrying a second grip.
Grips - Grips for holding the test specimen between the fixed member and the movable member of the test apparatus can be either a fixed or a self-aligning type.

5.2. Fixed grips are rigidly attached to the fixed and movable members of the test apparatus. Extreme care should be taken when this type of grip is used to ensure that the test specimen is inserted and clamped so that the long axis of the test specimen coincides with the direction of pull through the centerline of the grip assembly.

5.3. Self-aligning grips are attached to the fixed and movable members of the test apparatus. This type of grip assembly is such that they will move freely into alignment as soon as any load is applied if the axis of the test specimen will coincide with the direction of the applied pull through the centerline of the grip assembly. The specimens should be aligned as perfectly as possible with the direction of the pull so that no rotary motion will occur in the grips.

5.4. Deflection will be monitored from cross head movement. Extensometers are not needed or recommended for this test method.

5.5. Environmental Control Chamber to facilitate control of test temperature of 80± 1°C throughout the test. The chamber will have a means of controlling, maintaining, and recording the temperature throughout the test. The chamber must accommodate elongation of the specimen until break of the geomembrane.

6. Test Specimens

6.1. The test specimen shown in Figure 1, shall conform to the dimensions shown in Table 1. Test specimens shall be prepared by die cutting from roll goods samples, sheets, or coupons of the HDPE geomembranes. All surfaces of the specimen shall be free of visible flaws, scratches, or imperfections, especially around the edges of the specimen. If the specimen exhibits such marks, it shall be discarded and replaced with a perfect one. If these markings are present in the new specimen, then the die should be inspected for flaws and repaired.

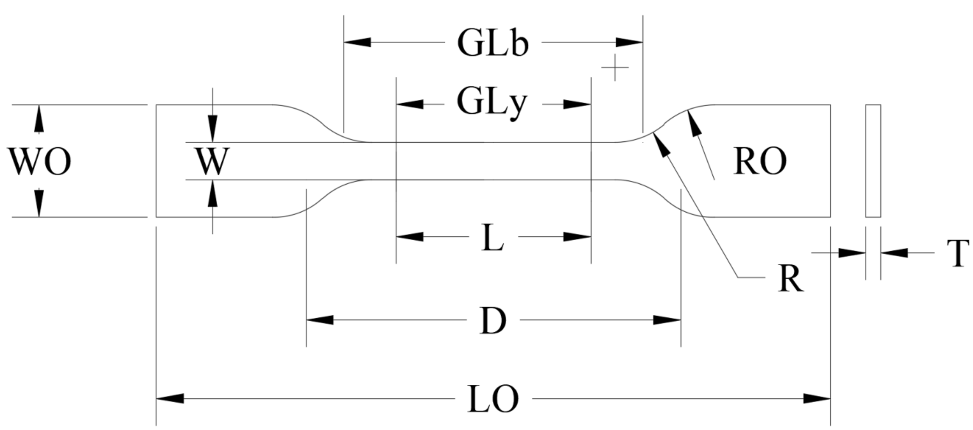

Figure 1. Plan and cross-sectional views of Type IV Dog Bone Specimen

Table 1. Specimen Dimensions for Type IV Dog Bone of Thickness, T, mm. (in.)

Description	Dimension, mm. (in.)	Tolerances, mm. (in.)
W - width of narrow section	6 (0.25)	±0.5 (± 0.02)
L - length of narrow section	33 (1.30)	±0.5 (± 0.02)
GLy - gage length for yield	33 (1.30)	±0.5 (± 0.02)
GLb - gage length for break	50 (2.0)	±0.5 (± 0.02)
WO - width overall	19 (0.75)	±6.4 (± 0.25)
LO - length overall	115 (4.5)	No max, no min
D - distance between grips	65 (2.5)	±0.13 (± 0.005)
R - radius of fillet	14 (0.56)	± 1 (± 0.04)
RO - outer radius	25 (1.00)	± 1 (± 0.04)

7. Conditioning

7.1. We know that the level of crystallinity and the associated residual stress are a function of cooling rate as the molten polymer solidifies. Even after the polymer reaches room temperature, the crystallinity and the associated residual stresses continues to change for a period before reaching near equilibrium if held in a controlled environment. It is felt that these continuing changes can affect test results. For this reason, it is recommended that geomembrane specimen be tested for strain hardening modulus between three (3) days and six (6) months after geomembrane fabrication.

7.2. The sample coupon needs to be annealed before specimens can be cut from it. This process should be conducted in a forced air oven at 100 degrees Celsius for one hour. The annealed sample coupon should be brought back down to standard laboratory temperature before specimens can be cut from it.

7.3. Specimens should be tested once the material has reached temperature equilibrium. The time required for this may vary depending on material type, manufacturing process, and material thickness. Testing should be conducted in a standard laboratory atmosphere of 21 ± 1°C.

8. Number of Test Specimens

8.1. Test ten specimens in the machine direction or cross-machine direction. The direction must be the same as ASTM D5397 test direction for proper correlation.

9. Speed of Testing

9.1. The testing speed shall be 7 mm/min (0.28 in/min) for all HDPE geomembranes tested.

9.2. Please note that this is intentionally slower than the typical ASTM D6693 speed. It has been shown that testing the specimen quickly generates elevated temperatures within the specimen which influences results in a negative manner.

10. Procedure

10.1. Confirm the width of the specimen by ASTM D374. Measure thickness of specimens according to ASTM D5199.

10.2. Place the specimen in the grips of the test apparatus, taking care to align the long axis with the point of attachment of the grips to the machine. The distance between the edges of the gripping surfaces should be 65 mm (2.5 inches) at the start of the test. Tighten the grips evenly and firmly to the degree necessary to prevent slippage of the specimen during the test, but not to the point where the specimen would be crushed. Set the speed of testing at 7 mm/min (0.28 in./min) and start the machine.

10.3. Record the load-extension curve and copy during the entirety of the test. It will be transformed into a stress versus strain curve as shown in Figure 2 by dividing the load by the actual cross-sectional area of the specimen's gauge area and then dividing the elongation by the gauge length at specified times during the test.

11. Calculations

11.1. After data and curves have been collected as shown in Figure 2, calculate the onset, modulus, and break point during strain hardening for each specimen.

11.2. To calculate the onset elongation, first draw a Casagrande curve fit line on the stress-strain curve. To do this, two straight lines should be drawn and connected: one which follows the flat part of the curve and another that follows the strain-hardening part of the curve, or the part that extends positively and ends at the breaking point. After this is done, define the elongation at the intersection point of these two lines. From there, this value is to be divided by 33 millimeters, which is the gage length for yield, then multiplied by 100%. This yields the onset elongation, as a percentage.

$$onset\ elongation\ percentage\ = \frac{elongation\ at\ intersection\ point}{33} X\ 100\%$$

11.3. To calculate the strain hardening modulus, determine the slope of the stress strain between the onset and the break points. Once this value is determined, it needs to be divided by the thickness of the material. This yields the strain hardening modulus, in units of Pascals.

$$strain\ hardening\ modulus\ = \frac{slope\ strain\ hardening\ portion\ of\ the\ curve}{thickness\ of\ material}$$

11.4. To calculate the break point elongation, first locate the break point on the curve and define the elongation at that point. From there, divide this value by 50 millimeters, which is the gage length for break, then multiply it by 100%. This yields the break point elongation, as a percentage.

$$break\ point\ elongation\ percentage\ = \frac{elongation\ at\ break\ point}{50} X\ 100\%$$

11.5. Lastly, compile the values found for onset, modulus, and break point, and compute the average, standard deviation, and coefficient of variation for each.

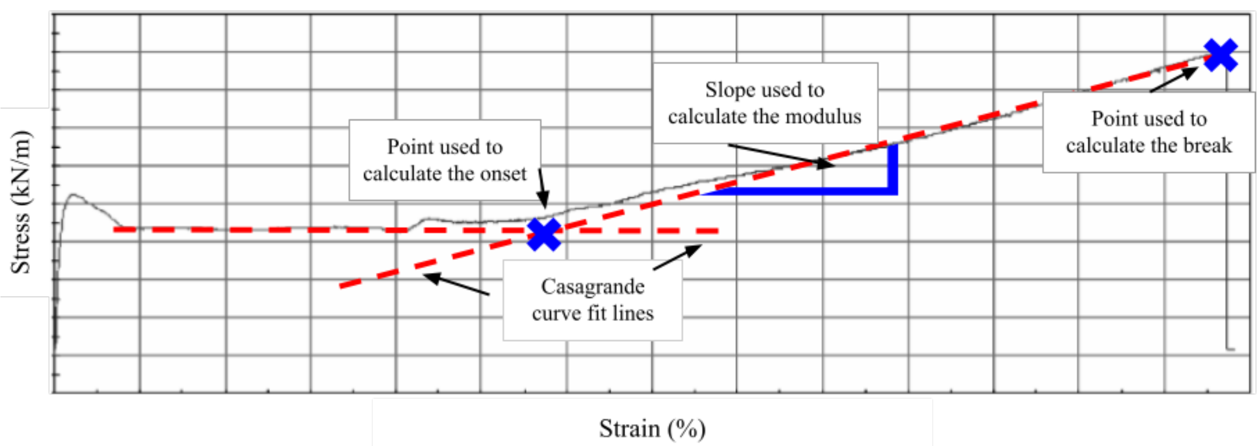

Figure 2. Example Stress Strain curve for HDPE Geomembrane

12. Report

12.1. Reports should include a complete identification of the materials tested, including type and manufacturer. Additionally, report the method (GM33), the method of preparing the specimens, conditioning, test temperature and the date of testing. Include the number of specimens tested, the speed of testing, the average, standard deviation, and coefficient of variation for the onset, modulus, and break points. Lastly, report the sheet extrusion method (i.e., flat die or blown film).

12.2. It is very important to note the direction in which the HDPE geomembrane was tested, either machine direction (MD) or cross-machine direction (X-MD).

13. Precision and Bias

13.1. No precision or bias has been established yet for this test standard.

14. Keywords

14.1. Strain hardening modulus; high-density polyethylene; slow crack growth; stress cracking

Adoption and Revision Schedule for GM33

"Determination of the Strain Hardening Modulus
as it relates to Stress Crack Resistance Characteristics of HDPE Geomembranes"

Adopted: 1/23/2022

Revision 1: Changed test temperature from 21 ± 2°C to 80 ± 1°C for better test repeatability and reproducibility.

Revision 2: Changed test temperature to 21 ± 1°C. Added section 7.2 on annealing sample coupon before specimens can be cut from it.