Assessing Performance of HDPE Geomembranes by the Multi-Axial Burst Test

J. E. Nobert
Poly-America, Grand Paririe, TX, USA

ABSTRACT

The multi-axial burst test is a tool that the design engineer can use in assessing the performance of HDPE geomembranes as landfill caps, where subsidence is problematic. In this test, pressure is applied perpendicularly to the surface of the geomembrane as would be the case in real life applications. Results from the multi-axial test confirm the results of the uni-axial tensile test for HDPE up to the yield point, but show that tensile break and ultimate elongation are not relevant to the liner's performance.

1 INTRODUCTION

Installed geomembranes are often stressed in more than one direction. A common test used to measure stress and strain on a geomembrane is the tensile test (ASTM D638). This test uses a relatively small specimen and only applies stress in one direction. This test may be good for comparison purposes or as a quality control test. However, it fails to predict how a liner will perform after it is installed, since most liners will experience bi-axial stresses.

In applications where subsidence is expected, such as landfill caps, the multi-axial burst test (MAB) can be considered a performance test. In the field where liners are covered by soil, the force is applied from above which then generates multi-axial stresses. Similar conditions exist in the multi-axial burst test where pressure is applied perpendicularly to the plane of the liner, causing the liner to deform. This information of pressure vs. liner deformation can be converted to stress-strain curves and used to assess the real performance of the installed liner.

This paper covers the response of HDPE geomembranes to the various conditions of the multi-axial burst test.

2 PROCEDURE

To perform the multi-axial burst test, a large hydrostatic pressure vessel is used (figure 1). The vessel has a diameter of 500 mm. and will allow for centerpoint deflections of 250 mm. Air pressure is controlled by an air pressure regulator.

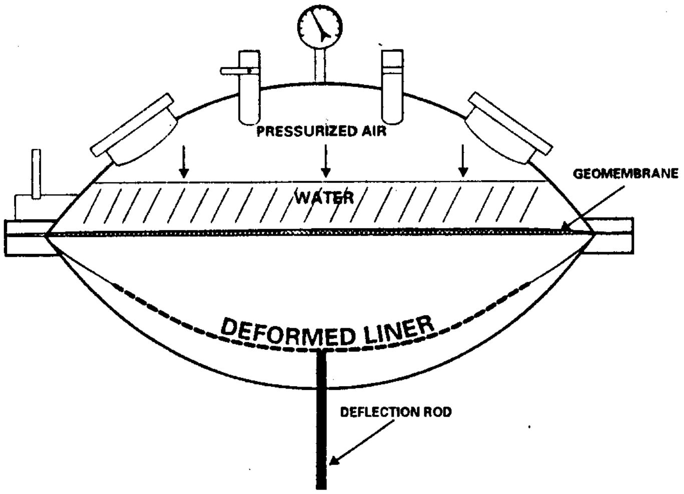


Fig. 1 Hydrostatic Pressure Test Vessel

The liner is placed across the open span of the pressure vessel and is clamped into place at the edges. Pressure is added at increments of 7 KPa/min. A more rapid rate of pressure increase does not allow the liner to reach steady state and prevents accurate measurements. After each increment of pressure, the deflection of the centerpoint rod is recorded. Testing occurs until the liner ruptures which is evident by a sudden loss of pressure. In most cases, failure of the liner will occur within half an hour.

For liners like HDPE which deform in a prescribed geometric shape (hemispherical), equations have been derived to calculate stress and strain values (figures 2 and 3). A more detailed progression of these mathematical expressions can be found in other sources.

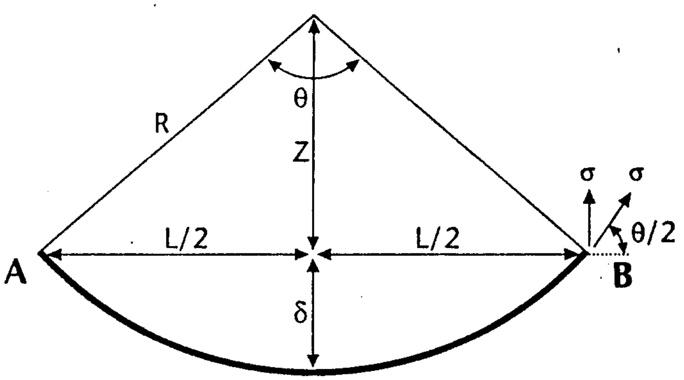


Fig. 2 Stress-Strain Geometric Diagram

STRESS

$$\delta = \frac{Lp}{4t*\sin(\delta/2)}$$

STRAIN

$$\epsilon = \frac{\text{arc } AB - L}{L} \cdot 100$$

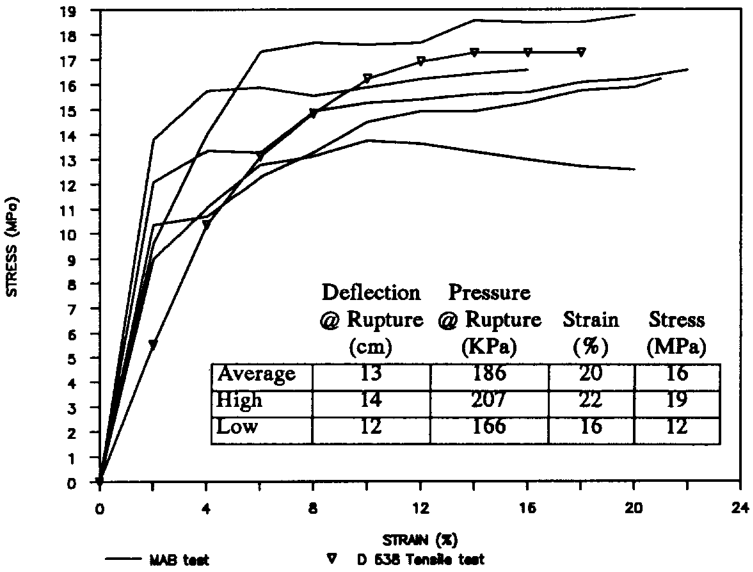
Fig. 3 Stress-Strain Equations

3 RESULTS

During the course of this work several different variables were investigated. These different variables are discussed below.

3.1 Test Variation

In any type of new test the first parameter to be investigated is the variability or data scatter of the test. Figure 4 plots the results of five different tests of 60 mil HDPE which were tested over a span of nine months. Since the samples used in this test were taken during different production runs, the graph shows not only the variability in the test, but the variability in the product. The table within the figure shows that the variation in deflection at rupture was approximately 8%, and the variation in pressure at rupture was 11%.



	Deflection @ Rupture (cm)	Pressure @ Rupture (KPa)	Strain (%)	Stress (MPa)
Average	13	186	20	16
High	14	207	22	19
Low	12	166	16	12

Fig. 4 Multi-axial Burst Test Variation of 60 mil HDPE

Also graphed in this figure is a ASTM D638 tensile curve (up to the yield point) of 60 mil HDPE. As will be noted, this curve is similar to the multi-axial curves. Unlike the index tensile test which shows HDPE liners elongating to over 800% before rupture, the multi-axial burst samples show that rupture occurs at strain values of around 16%.

In reviewing the failed multi-axial burst samples, it was observed that the entire lot of samples were fairly uniformly deformed, with the exception of the area where the rupture occurred. The gauge of the sample had not changed significantly. Again, this is what is expected from the uni-axial tensile test. The first sign of failure with HDPE in the multi-axial burst test, is the formation of a cat eye. This usually occurs at the thinnest spot on the sample, but could occur at some other weak spot or defect. This cat eye grows in length and depth. The liner will thin out within this cat eye and finally fail. Although it could not be measured, it is speculated that this region may have undergone the elongation that is typically reported for tensile elongation at break (800%). The remaining area of the samples is virtually unaffected, except for being bowl shaped.

3.2 Thickness

With the uni-axial tensile test (ASTM D638), stress-strain values which are normalized for thickness are unaffected by changes in gauge. Table 1 shows the multi-axial burst results of different thicknesses of HDPE liner. As with the uni-axial tensile test, the multi-axial test shows that gauge does not change the stress-strain values at rupture for HDPE. However, this table does show that the pressure, which is analogous to force in the uni-axial test necessary to cause rupture, does vary proportionally to changes in thickness. Centerpoint deflection, which is analogous to elongation, does not change with gauge, as expected.

Thickness (mm)	0.75	1.00	1.50	2.00	2.50
MAB Stress @ Rupture (MPA)	16	18	16	17	17
Pressure @ Rupture (PA)	83	124	186	221	290
D638 Force @ Yield (PA)	83	111	167	222	278
MAB Stress @ Rupture (%)	16	16	21	15	20
Deflection @ Rupture (cm)	12	13	14	12	13
D638 Elongation @ Yield (cm)	60	60	60	60	60

* MAB = Multi-axial
D638 = Uni-axial

Table 1 Effect of Thickness

3.3 Textured Sheet

Much controversy surrounds the index tensile properties of textured sheet. Because of the differences in the manufacturing processes, the textured layer may have different adhesion to the core layer. In the co-extrusion process, the textured layer and the core layer act in unison. Because of this and because the textured layer causes stress focal points, the ultimate tensile properties are reduced. Textured sheet products, which do not have perfect adhesion with the core layer, will tend to have higher ultimate tensile properties (table 2).

Table 2 also shows that the liner's true performance under multi-axial stress is not dependent upon its ultimate tensile properties, but is a function of its yield properties. This does not mean that ultimate tensile properties are totally irrelevant. With smooth liners the tensile at break and ultimate elongation values can indicate imperfections, or can yield information on the quality of the material used to make the sheet (IE. regrind). However for textured sheet, which, by design, has controlled imperfections (stress focal points), tensile break and elongation at break values are totally irrelevant once the liner has reached its yield point.

	Smooth	Co-extruded Textured	Sprayed Textured
D638 Tensile			
Yield (MPa)	17	17	17
Elongation @ Yield (%)	18	18	18
Break (MPa)	31	14	21
Elongation @ Break (%)	800	200	600
MAB			
Stress @ Rupture (MPa)	19	17	16
Strain @ Rupture (%)	20	23	21

Table 2 Textured vs. Smooth HDPE Liner

3.4 Reinforcement With Geotextiles

Geotextiles typically are used for filtration or to act as a cushion against sharp objects in the subgrade. In performing multi-axial burst tests, it has been found that geotextiles serve to not only strengthen the liner, but increases the liner's ability to deform by over 50%. Table 3 shows that a 270 gm/sq.m needlepunch polypropylene beneath a 1.00 mm HDPE liner requires the same amount of force to cause rupture as a 2.00 mm HDPE sheet by itself. Likewise, a 540 gm/sq.m textile with a 1.00 mm sheet is equivalent in performance to a 2.00 mm sheet with a 270 gm/sq.m textile.

Geomembrane Thickness (mm)	1.00	1.00	1.00	2.00	2.00	2.00
plus Geotextile Thickness (gm/m²)	-	270	540	-	270	540
Multi-axial Burst Results						
Force @ Rupture (kN/m)	18	31	42	32	44	54
Strain @ Rupture (%)	16	38	29	18	27	33

Table 3 Reinforcement Effect of Geotextiles

When rupture did occur, the typical cat eye did not form in the HDPE geomembrane. Instead, it is believed that the textile tore first which immediately triggered the failure of the liner. The liner then tore over the spot of the failed textile.

3.5 Temperature

In many applications, the liner will be exposed to extremes of temperature. Since these changes could have a great impact on the performance of the liner, it was important that this variable be investigated for multi-axial burst testing. Temperatures during this study varied between -25° C. and 65°C. which were considered the normal extremes that a liner would be subjected to.

As expected, as temperature was lowered from ambient conditions, the stress to cause rupture increased and the strain decreased, and the opposite occurred as temperature was increased from ambient. Table 4 shows that these changes generally agree with values obtained from ASTM D638 tensile testing.

Temperature (° C.)	-25	0	23	40	50	60
MAB Stress @ Rupture (MPa)	26	19	16	15	12	12
D638 Tensile @ Yield (MPa)	26	22	19	16	14	10
MAB Strain @ Rupture (%)	13	20	21	23	26	42
D638 Elongation @ Yield (%)	12	15	18	18	21	27

Table 4 Effect of Temperature on HDPE

3.6 Chemical Resistance

Chemical compatibility of HDPE can be one of the most difficult parameters to assess. Most testing relies on index tests which may not yield true information as to how a liner will perform in the field.

With a modification to the chemical immersion tanks, the full multi-axial sample was immersed in the chemical of interest for seven days. After it was removed, it was immediately placed into the test chamber. A composite summary of the results is shown in table 5.

Comparing the results from the multi-axial burst test to results from tensile tests, it generally can be stated that chemicals that affect the results in a tensile test will also effect multi-axial burst results. Of particular concern are the chlorinated hydrocarbons and aromatics. These materials are soluble in the polyethylene and tend to plasticize the liner as evidenced by the reduced stress values. As expected, most inorganic acids and alcohols have little or no effect.

Chemical Class	Chloronated Hydro–carbon	Alcohol	Aromatic	Inorganic Acid	Control
MAB					
Stress @ Rupture (MPa)	12	15	12	16	16
Strain @ Rupture (%)	12	17	22	20	18
D638					
Tensile @ Yield (MPa)	15	17	14	17	17
Elongation @ Yield (%)	23	17	21	18	18

Table 5 Chemical Compatibility of HDPE Multi-axial Burst vs. D638 Tensile

4 CONCLUSION

The multi-axial burst test has proven to be a useful tool in evaluating geomembranes and even other types of geosynthetics. The liners can be subjected to a variety of conditions that more closely simulate field conditions. Comparisons to ASTM D638 tensile tests show that in many cases the multi-axial burst test will mimic the uni-axial test, but only up to the yield point. This test also proves that ultimate tensile properties obtained from ASTM D638 testing does not reflect the true performance of the liner. However, the multi-axial burst should not replace the uni-axial test. The uni-axial tensile test is still the best test to determine roll-to-roll quality on smooth liner.

REFERENCES

Beyer, W. H., (1987) *Standard Mathematical Tables*, 28th Edition CRC Press, Inc.; Boca Raton

GRI Test Method GM-4, (1989) *Three Dimensional Geomembrane Tension Test*, Geosynthetic Research Institute, Philadelphia