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A COMPARISON OF HIGH DENSITY POLYETHYLENE (HDPE) AND LINEAR LOW DENSITY POLYETHYLENE (LLDPE) GEOMEMBRANES

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ABSTRACT

High density polyethylene (HDPE) geomembranes have been widely used in landfill, impoundment, sludge ponds, and other geosynthetic applications. HDPE has many advantages when it comes to chemical resistance and UV stability. However, the relatively limited puncture resistance and low extensibility in a multi-axial mode of HDPE could be a disadvantage in applications where these properties are desirable. Linear low density polyethylene (LLDPE) geomembranes exhibit significantly better multi-axial extension properties and index puncture resistance properties than HDPE geomembranes of the same nominal thickness.

This paper compares the properties of these two materials with supporting laboratory test results. Also presented are summary results from more performance related evaluations.

INTRODUCTION

Geomembranes have been successfully used as fluid barriers in the United States for many different applications. In this role, the geomembrane materials must be durable to withstand the rigors of the application. National Seal Company currently offers two types of geomembranes to service the needs of those with fluid containment applications. These products are high-density polyethylene (HDPE), linear low-density polyethylene (LLDPE).

MATERIALS

The HDPE and LLDPE geomembranes in use are based on the ethylene monomer and may include a comonomer. The resin for these materials is combined with a stabilizer package that typically includes carbon black and other antioxidants. These stabilizers provide protection during processing and from the effects of aging in the field. The resin package is then formed into a sheet through the extrusion process. This can take one of two forms. Either the polymer is extruded through a flat die, or through a circular die.

If the flat die is used, the resin is introduced into the machine where heat and pressure are applied as a screw forces the polymer down the length of the barrel. The molten polymer enters a die at the opposite end, and exits as a flat sheet onto a stack of chill and finishing rollers. From there, the sheet proceeds to the wind-up section where it is wound on a core into continuous rolls. National Seal Company currently has the widest continuous flat sheet extrusion process in the world for polyethylene geomembranes at a width of 9.3 m.

If a circular die is used, the process is nearly identical until the end step. The polymer enters the circular die through the center via a number of radial feed ports. These ports feed a circular chamber which forms a tube of molten polymer. The tube exits the die as a ring assisted by a set of rolls, and is then inflated to a pressure that will fix the circumference. The exit direction of the tube is usually upward into a tower. At the top, the tube is slit and opened into a flat sheet that is then wound onto a roll [1].

PHYSICAL PROPERTIES

Selected physical properties are given for the HDPE and LLDPE geomembranes in Table 1. Please note that the values for puncture resistance, tear resistance, multi-axial elongation, and critical cone height were determined for 2.0 mm geomembrane. The water vapor transmission reported in Table 1 corresponds to 1.5 mm geomembrane.

Table 1
Selected Physical Properties
Typical Values

Property	LLDPE	HDPE
Density (g/cc)	0.92	0.94
Water Vapor Transmission (g/m^2-day)	0.027	0.009
Ultimate Tensile Strength (mPa)	35.2	32.9
Puncture Resistance (N)	623	770
Tear Resistance (N)	258	298
Multi-Axial Elongation (%)	65	30
Critical Cone Height (cm)	9	2

The density of the materials was measured according to ASTM *D1505 Test Method for the Density of Plastics by the Density-Gradient Technique*. This property is related to the crystallinity of the material. In general, a higher density is an indicator of better chemical resistance.

The water vapor transmission test was conducted according to ASTM E96 *Test Methods for Water Vapor Transmission of Materials*. This test involves clamping a specimen over a cup that contains a quantity of water. The specimen is clamped such that the only way for the water inside the cup to escape is by vapor diffusion through the geomembrane. During the test, the total weight of the cup, specimen, and clamp is monitored over a period of time. The weight data, recorded temperature and relative humidity, and specimen dimensions are then used to calculate the water vapor transmission rate. These materials are all relatively impermeable.

The ultimate tensile strength was evaluated according to ASTM D638 *Test Method for Tensile Properties of Plastics*. This test method is considered an index test and involves a standard specimen often called a "dogbone" in the United States because of its shape. The specimen has a width dimension of approximately 6 mm in the test area. The test is run at 500 mm/min for relatively flexible materials like LLDPE, and 50 mm/min for relatively stiff materials like HDPE. The strengths shown in the table are a function of the flexibility of the material involved and the test speed.

The puncture resistance was determined according to ASTM D4833 *Test Method for Index Puncture Resistance of Geotextiles, Geomembranes, and Related Products*. The specimen in this test is clamped into a holder with an exposed test area having a diameter of 45 mm. The rod used to puncture the geomembrane has a diameter of 8 mm with a flat end having a 45° chamfered edge in contact with the material. The puncture probe is forced through the specimen at a rate of 300 mm/min until a failure is recorded. Stiffer materials tend to have a higher puncture resistance as can be seen in Table 1.

The tear resistance was evaluated according to ASTM D1004 *Test Method for Initial Tearing Resistance of Plastic Film and Sheeting*. This method involves clamping a specimen with a 90° notch into a tensile testing machine. During the test, the tear starts at the apex of the notch and propagates across the test specimen. The peak load is recorded and reported as the resistance to tearing. This particular value is sometimes viewed as a rough indicator of resistance to installation damage for a geomembrane. Of the geomembranes presented here, the PP has the lowest resistance to tearing.

The multi-axial tensile properties of the geomembrane were tested according to ASTM D5617 *Test Method for Multi-Axial Tension Test for Geosynthetics*. The multi-axial tension test involves clamping a circular specimen over a test chamber having an open test area diameter of 61 cm. Air is introduced into the lower half of the test chamber (below the test specimen) at a rate of approximately 7 kPa per minute. As the geomembrane is pushed upwards, the magnitude of the deflection is measured. Some devices use a mechanical measuring device to monitor deflection. At National Seal, a measuring device utilizing ultra-sonic sensing technology records the deflection of the geomembrane. This information is then used to calculate the stress and, perhaps more importantly, the elongation of the geomembrane at burst. As might be expected, the more flexible geomembranes can withstand much greater elongation before bursting than the more rigid geomembranes.

The puncture resistance of the geomembranes is also evaluated in a test that is closer to a "worst-case" performance situation in the critical cone height test. This test is conducted in accordance with ASTM D5514 *Test Method for Large Scale Hydrostatic Puncture Testing of Geosynthetics*. This evaluation consists of placing a geomembrane specimen over a set of three truncated cones in a pressure vessel, and applying pressure over the top of the geomembrane until a failure occurs or until the maximum pressure of the device is reached (generally about 690 kPa). The cones in this test are truncated such that the truncated face makes a 45° angle with the base of the cone. The cones are arranged in the test device so that the geometric center of the cone is on a circumference of a 200 mm diameter circle.
The test area in the National Seal device has a diameter of 610 mm . They are placed 120° apart on the circle with their 45° faces each facing the center of the test area. The height of the cones relative to a subgrade of sand is varied until the largest cone height that the geomembrane can resist without failure is reached. As is indicated in Table 1, the more flexible materials are likely to conform more readily to an aggressive subgrade than a stiffer geoemembrane. It should also be noted that this test can accommodate site specific subgrades in the evaluation instead of truncated cones.

CHEMICAL RESISTANCE

Resistance of HDPE and VLDPE to Sulfuric Acid

In 1990, a long term immersion study was conducted to evaluate the effect of sulfuric acid on an HDPE geomembrane [2]. The geomembrane was immersed in 10% (by volume) solution prepared from reagent grade, concentrated sulfuric acid and distilled water. Sufficient samples of 22 cm x 28 cm coupons were immersed to provide testing for exposure periods of 2, 4, 6, 8, 16, and 24 weeks. The coupons were suspended in glass tanks to allow for free flow of solution, and the tanks were filled such that essentially zero headspace remained. The tanks were kept at a constant temperature of 23° C. The geomembranes were tested at each exposure period for tensile properties, thickness, weight changes, dimensional changes, and volatile loss (a test for how much material has been absorbed into the geomembrane).

The results of this study suggested that National Seal Company's HDPE geomembrane was unaffected by the continuous exposure to the sulfuric acid solution. The tensile properties remained within 10% of the original, unexposed values. The coupon length, width, thickness, weight, and volatile loss were virtually unchanged. A summary of the results of this test is shown in Table 2.

Table 2
HDPE versus 10% Sulfuric Acid
Selected Results

Property	Unexposed	4 Weeks	16 Weeks	24 Weeks
Tensile Stress at Break (mPa)	30.5	31.0	32.0	31.3
Tensile Strain at Break (%)	869	918	925	901
Length Change (%)	N/A	0.0	0.0	0.0
Width Change (%)	N/A	0.0	-0.4	-0.4
Thickness Change (%)	N/A	+0.2	0.0	+0.2
Weight Change (%)	N/A	+0.4	+0.1	+0.1
Volatile Loss (%)	0.02	0.01	0.01	0.01

We have not repeated the sulfuric acid exposure with the LLDPE geomembrane, but an exposure with sulfuric acid and very low density polyethylene (VLDPE) geomembrane was conducted along with the HDPE geomembrane study. The VLDPE in this case had a density of approximately 0.900 g/cm^3, suggesting that it may be somewhat less chemically resistant than the LLDPE geomembrane. The solution, test conditions, and exposure periods were the same as those used in the HDPE study. The results were of this study were also the same. The VLDPE geomembrane experienced virtually no change in tensile properties, coupon dimensions, weight, or volatile content over the course of the exposure. The results of this study suggest that the LLDPE geomembrane would also be resistant to exposure to sulfuric acid under the same conditions. A summary of the data for the VLDPE geomembrane is shown in Table 3.

Table 3
VLDPE versus 10% Sulfuric Acid
Selected Results

Property	Unexposed	4 Weeks	16 Weeks	24 Weeks
Tensile Stress at Break (mPa)	26.6	27.8	27.7	29.7
Tensile Strain at Break (%)	1243	1304	1280	1300
Length Change (%)	N/A	0.0	0.0	0.0
Width Change (%)	N/A	-0.5	-0.4	-0.5
Thickness Change (%)	N/A	0.0	+0.4	+0.2

Weight Change (%)	N/A	0.0	+0.1	0.0
Volatile Loss (%)	0.03	0.02	0.05	0.07

It is important to note that VLDPE is no longer available on the market, and these results are presented only to provide a comparison to the HDPE geomembrane and to provide some basis for judging the effect of a similar exposure to LLDPE geomembrane.

Resistance of HDPE and LLDPE Geomembranes to MSW Leachate

In the United States, EPA Test Method 9090 has been used as a protocol to evaluate the chemical resistance of a geomembrane to a test liquid. This test protocol is being replaced with a series of ASTM standard test methods, but the procedure is essentially the same. The protocol involves immersing samples of the geomembrane in the liquid it is intended to contain at 23° C and 50° C. Coupons are removed from the leachate at 30, 60, 90, and 120 days and subjected to a series of tests. The results of the tests versus time are then evaluated to determine whether or not a significant change had occurred. The important considerations are whether any change in test value is consistent over time, and whether the change is reflected in more than one type of test. It has been found with geomembranes that the test results can fluctuate ±20%, but still not show that a consistent change has occurred over time or between types of tests (i.e. the geomembrane was not significantly affected by the test liquid).

The HDPE and LLDPE geomembranes, have all been evaluated using the EPA Method 9090 test protocol and a leachate from a municipal solid waste (MSW) facility in the State of Pennsylvania [3]. The HDPE geomembrane in this evaluation was 1.5 mm thick, and the PP and LLDPE geomembranes were both 1 mm thick products. The results for all three materials suggested that the leachate had no significant effect on the physical properties.

Selected results of the exposure of the HDPE and LLDPE geomembranes to the MSW leachate are shown in Table 4 and Table 5. The results of these immersion studies indicated that the three geomembrane materials were suitable for containment of this MSW leachate.

Table 4
HDPE versus MSW Leachate
Selected Results

Property at 23°C	Unexposed	30 Days	60 Days	90 Days	120 Days
Tensile Stress at Break (mPa)	40.2	40.0	39.9	41.4	39.6
Tensile Strain at Break (%)	1031	1059	1016	1088	1009

Property at 50°C	Unexposed	30 Days	60 Days	90 Days	120 Days
Tensile Stress at Break (mPa)	40.2	39.6	39.0	40.3	41.1
Tensile Strain at Break (%)	1031	999	1020	1086	1081

Table 5
LLDPE versus MSW Leachate
Selected Results

Property at 23°C	Unexposed	30 Days	60 Days	90 Days	120 Days
Tensile Stress at Break (mPa)	42.7	35.2	41.9	39.2	41.0
Tensile Strain at Break (%)	1120	1178	1088	1085	1109
Property at 50°C	**Unexposed**	**30 Days**	**60 Days**	**90 Days**	**120 Days**
Tensile Stress at Break (mPa)	42.7	35.7	39.4	39.8	41.3
Tensile Strain at Break (%)	1120	1212	1036	1117	1129

ULTRA-VIOLET (UV) RESISTANCE

In an exposed application, the primary source of degradation of geomembranes comes from sunlight. In particular, the ultra-violet (UV) portion of the spectrum has enough energy to break down the polymers that comprise the geomembranes discussed in this paper. In order to defend against degradation, the geomembranes are manufactured with additives to absorb the UV energy and/or halt the harmful reactions.

It is not a simple task to evaluate the effectiveness of these practices in halting the degradation of the materials. The time required for meaningful results in a real-world exposure may be measured in years. This is not a practical amount of time in which to wait for something in a fast-paced industry. Another way to evaluate the materials would be to use a test that accelerates the process so that results can be achieved in a more reasonable time period.

National Seal Company has conducted a study utilizing a fluorescent UV/condensation apparatus to evaluate specimens of 1.5 mm HDPE and 1 mm LLDPE geomembranes [4]. This device exposes the specimens with fluorescent UVA-340 lamps that emit UV radiation in the band from 295 nm to 400 nm with the peak emission at 340 nm. The specimens were exposed to a cycle of 20 hours of continuous UV radiation at a temperature of 75° C, and a 4-hour cycle of condensation at a temperature of 60° C. The device is equipped with an internal reservoir of water to provide the moisture needed for the condensation cycle. Periodically, specimens were removed and evaluated for index tensile properties (ASTM D638). The results of this testing are shown in Table 6.

Table 6
UV Exposure Evaluation
20 hours UV at 75°C/4 hours Condensation at 60° C
Index Tensile Property Result Summary

Property	Unexposed	2400 Hours	5600 Hours	8000 Hours
HDPE Stress at Break (mPa)	35.7	34.7	28.7	31.0
LLDPE Stress at Break (mPa)	39.5	38.9	23.9	9.0
HDPE Strain at Break (%)	892	839	709	766
LLDPE Strain at Break (%)	982	1067	620	152

One way to select an end-point for accelerated testing is to consider the material to have failed when the property being evaluated has reached 50% of its unexposed value. In Table 6, it is clear that the LLDPE geomembrane specimens had reached this point by the 8000 hour level in terms of the tensile stress and strain at break. The HDPE specimens had only declined 13.3% from the unexposed tensile stress at break and 14.1% from the tensile strain at break.

These test results suggest that under the conditions of this exposure, the HDPE material is more resistant to degradation. However, it must be noted that no correlation exists to equate these exposure conditions to real-world exposure conditions.

INTERFACE FRICTION CHARACTERISTICS

Slope stability is a design concern for many applications, and past failures have illustrated the limits of using a smooth HDPE geomembrane with a relatively low coefficient of friction on side slopes. In response to this the geomembrane manufacturers have developed a number of ways to modify the material so that the interface coefficient of friction is increased.

The current techniques all involve manufacturing a textured surface of some type onto the geomembrane. These methods include blown coextrusion, embossing, extrusion coating, and sprayed coatings [5].

In blown coextrusion, a blowing agent and a nucleating agent are combined with the outer layers of a three layer coextruded polymer on a blown film manufacturing line. As the polymer progresses to the opening of the die, the pressure decrease allows the gas to migrate to the surface and form a foam. Shearing forces then break the bubbles in the foam which forms the textured surface on the geomembrane.

The spray coating process is secondary in nature in that it is done after the manufacture of the geomembrane. In this method, the molten polymer is pumped to a high pressure and then droplets are sprayed onto the geomembrane as it passes beneath the spray nozzles.

The embossing technique is accomplished with engraved rollers in the first and second nips of a flat sheet extrusion line. This technique allows the pattern to dictate the level of interface friction desired for each side of a geomembrane. Different patterns can be applied to the top and bottom of the sheet.

The extrusion coating method is another secondary process applied to already manufactured geomembrane. A flat sheet die is used to extrude a foamed coating onto the surface of the geomembrane as it passes underneath. As in the blown coextrusion process, the shearing action of the flow through the die and the movement of the sheet beneath the foam break the bubbles to produce the desired textured coating on the surface of the geomembrane.

The texturing can make a dramatic difference in the interface friction properties as measured in a direct shear device. For example, in direct shear interface tests conducted at National Seal Company [6] under relatively low normal stresses (20 Kpa to 62 Kpa) a peak angle of 9° was found for a smooth HDPE vs. a nonwoven needle-punched geotextile under dry conditions. A test under the same conditions with a textured HDPE geomembrane vs. a nonwoven needle-punched geotextile generated a peak friction angle of 35°. The texturing in this case was applied with the extrusion coating method.

Similar results have been documented comparing smooth LLDPE geomembrane with smooth LLDPE. The interface direct shear test is conducted in accordance with ASTM D5321 *Determining the Coefficient of Soil and Geosynthetic or Geosynthetic and Geosynthetic Friction by the Direct Shear Method*. This test method involves a 30 cm by 30 cm contact area between the interfaces, and so can be considered more of a performance test. It is important to note that this particular evaluation can be affected by many variables. Historical test results should be used for guidance purposes only, and not be expected to replace site specific testing.

DISCUSSION

HDPE and LLDPE geomembranes can all be used effectively to contain liquids. The advantage of one material over another must be based on a series of factors. Among these factors are; flexibility, resistance to installation damage, resistance to degradation from chemical or UV exposure, puncture resistance while in service, and interface friction considerations. It is expected that HDPE geomembranes offer better chemical and UV resistance than LLDPE geomembranes. However, there will be situations where the resistance to degradation is not as much a concern as, for example, the flexibility of the geomembrane. In such a case the LLDPE materials may be superior. In situations where greater interface resistance to shear forces is required, a textured geomembrane may be more desirable.

It is important in any material selection process to gather as much information as possible, and conduct site specific testing where necessary to determine which geomembrane material will be best suited to the application.

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