The Environmental Stress Crack Behaviour of Coextruded Geomembranes and Seams

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ABSTRACT: Three-layered coextruded geomembranes composed of a core of very low density polyethylene (VLDPE) and skins of high density polyethylene (HDPE) possess a unique combination of properties. They have shown better puncture resistance and multiaxial elongation than HDPE and better tensile strength, tear resistance, and chemical resistance than VLDPE. This paper will present the results of recent constant load environmental stress crack resistance (CLESCR) tests that were performed on several coextruded products including textured sheet and two types of seams (fusion and extrusion). The results showed that coextruded geomembranes and seams have much better stress crack resistance than conventional HDPE geomembranes.

1 INTRODUCTION

1.1 Coextruded Geomembranes

Coextrusion is the process of combining two or more molten plastic streams into a single sheet during the sheet manufacturing process. Although this concept was introduced to the geosynthetics community only a few years ago (Kolbasuk, 1991) it has been used in the packaging industry for over twenty years. The basic premise of this technology is that special properties can be obtained by joining together polymers with different properties.

A typical coextruded geomembrane (COEX) has a core made from VLDPE and skins made from HDPE. This is illustrated in Fig. 1. It is important to note that since the process involves combining the layers while molten, there is no seam. The layers are intimately mixed and cannot be separated.

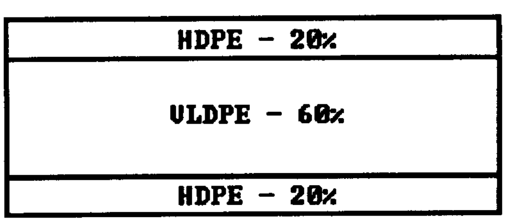

Fig. 1 Cross Section of a Coextruded Geomembrane

Some of the properties of coextruded geomembranes are shown in Table 1. Notice first that the density of the combined materials is around 0.930 g/cm³. If one were to change the density of a geomembrane from 0.948 to 0.930 g/cm³, several property changes would occur. First, the strength would be reduced while the stress crack resistance and flexibility would be increased. Also, the chemical resistance and weatherability would both be reduced by lowering the density. The same thing is true for the coextruded geomembranes except that they retain the excellent chemical resistance and weatherability of HDPE. Notice that the permeation rate of COEX is close to HDPE and much lower than VLDPE.

The values in the table also show that the strength properties (yield stress, tear, puncture) of COEX are reduced while the properties that require the absorption of energy like elongation and impact become more favorable compared to HDPE.

Two properties of particular interest for landfill applications are the critical cone height and the multiaxial elongation. The cone height is sometimes used to determine the maximum allowable size of stones in a subgrade and the multiaxial elongation demonstrates a liner's ability to accommodate large strains during its service life. Notice that the coextruded geomembrane is more suitable in both of these cases.

Table 1 Comparison of Properties

Property	HDPE	COEX	VLDPE
Density[1] (g/cm^3)	0.948	0.930	0.920
Yield Stress (MPa)	17.6	10.6	7.6
Yield Strain (%)	17	20	85
2% Secant Modulus(MPa)	540	420	90
Tear Strength (Kg)	24	16	17
Puncture Strength (Kg)	60	43	44
Tensile Impact Strength (J)	34	104	115
Critical Cone Height (cm)	1.5	4.0	6.5
Multiaxial Elong. (%)	25	45	110
Permeation Rate, MEK (μg/cm^{2}min)	0.11	0.17	0.77

[1] Including carbon black

1.2 Environmental Stress Cracking

Stress cracking or slow crack growth is a property that may limit the service lifetime of some medium and high density polyethylene geomembranes in certain applications. It occurs when a specifically shaped defect or stress raiser develops into a growing crack, which may eventually grow through the sheet. Some of the factors which influence how quickly a crack grows include the size and sharpness of the defect, the load, the temperature, and the inherent fracture toughness of the material. Additionally, some chemicals can also accelerate the crack growth. The process is known as environmental stress cracking when chemicals are involved.

Of the factors mentioned above, the fracture toughness of the material is very important. In fact, it is well known that a series of medium density polyethylene resins can vary three or four orders of magnitude in stress crack resistance.

There have been three tests used to evaluate the ESCR of HDPE geomembranes. The first was the bent-strip test (ASTM D1693) which turned out to be inappropriate for geomembranes. The test involves placing a notch in a specimen and bending it 180° to place it under load. However, the stress is quickly relieved by the resin's ability to stress relax. Therefore, once the load is effectively removed, the notch will not grow into a crack. The result is that this test cannot distinguish different resins.

The second and most common test being used today is the notched constant tensile load test (ASTM D5397). This test also involves a notched specimen, but it is held under a constant load to prevent stress relaxation. This test is typically performed at 50°C and has proven to be a useful tool for evaluating the ESCR of different resins and smooth geomembranes. This test was used to compare HDPE with COEX and VLDPE and the results are shown in Table 2.

Table 2 ESCR of Polyolefin Geomembranes by ASTM D5397 (Single Point at 30% of Yield Stress)

Geomembrane	Time-to-Failure(Hrs)
HDPE	450
COEX	>10,000
VLDPE	>10,000

This table shows the dramatic improvement in stress crack resistance displayed by coextruded geomembranes. The exact reason they perform so well is not known, but it seems that cracks simply do not grow through the VLDPE layer.

Figure 2 shows a thin cross-section microtome of a notched COEX specimen after being tested at 50°C for several hundred hours followed by several hundred more hours of exposure at 80°C. The dark layer is the HDPE skin. Notice first that the notch became round and flat. Secondly, it looks like the VLDPE layer somehow elongated into the HDPE layer to relieve the stress. The bright conical shaped area is believed to be where crazing had occurred without crack propagation. This photo clearly shows that the VLDPE layer acts as a crack terminator during the ESCR test. It should be stated that the initial notch was not as deep as the 20% specified in ASTM D5397 because the entire HDPE layer is 20% of the thickness.

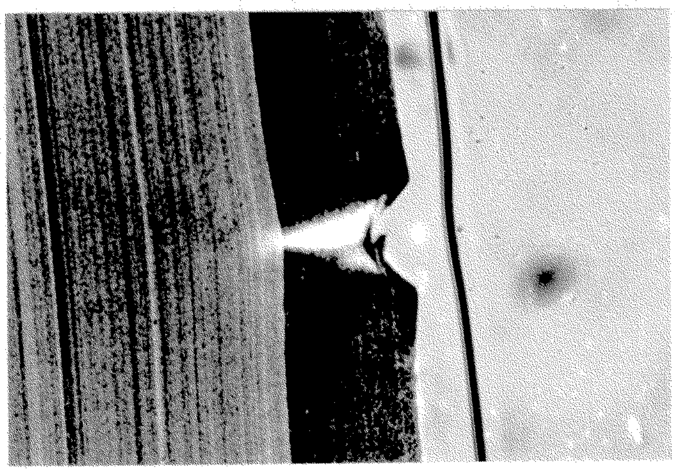

Figure 2 Photomicrograph of the Notch in a COEX Specimen After Exposure in an ESCR Test at 80°C (Magnification - 100X).

A third stress crack test for evaluating textured geomembranes and seams has been recently reported (Thomas, 1993). This test is also a constant load test but does not require a notch. Instead, a specimen with more surface area is used and the test is run at 80°C to accelerate the crack growth rate. This test was used to evaluate the stress crack resistance of HDPE smooth sheet, textured sheet, and fusion seams. Preliminary results were also presented concerning the ESCR of coextruded products.

The purpose of this paper is to present the final results of some of the tests described before (Thomas, 1993) and to present new results on extrusion seams.

2 EXPERIMENTAL

A schematic of the constant load ESCR test device is shown in Figure 3.

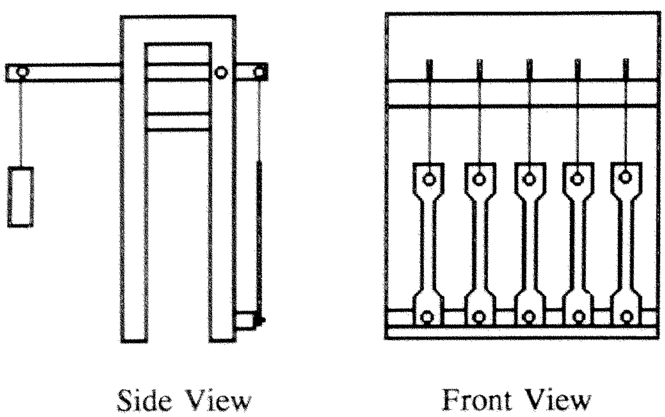

Figure 3 Schematic of ESCR Test Device

The test specimens were securely mounted to the frame and to one end of a lever arm that had a load applied to the other end. The fixture was mounted on the side of a constant temperature bath which contained the stress crack accelerating agent. Other experimental conditions are shown in Table 3.

Table 3 Experimental Conditions

Parameter	BAM ESCR Test
Specimen	ASTM D638, Type I
Load	2.4 or 4.0 MPa
Temperature	80°C
Solution	5% Igepal CA 720

The specimen was larger than the one used in ASTM D5397. The Type I is much longer and the narrow region surface area is 1000 mm^2 compare to 45 mm^2 for the D5397 specimen. This is an important factor because a crack initiation site is needed to begin a stress crack. A larger surface area means that more potential sites are available.

The load for this test was fixed at 4.0 MPa for HDPE specimens and 2.4 MPa for coextruded specimens. These loads produced identical strains for both types of specimens. Since the coextruded specimen had a lower yield stress, it simply stretched under 4.0 MPa of load and did not break. Therefore, placing the specimens under loads to produce a constant initial strain was chosen to compare the two types of materials.

The temperature was higher than the one used in D5397. This was necessary to grow a crack in a reasonable period of time.

The surfactant was also different than the Igepal CO 630 commonly used in D5397. This change was required because the CO 630 became insoluble in water at about 55°C, while the CA 720 can be used at temperatures up to 85°C.

This test was performed on three different sets of specimens to compare the performance between HDPE and COEX. The first set was 2.0 mm textured sheet made by an extrusion coating process. The HDPE and COEX samples were coated under the same conditions. The second set of specimens were 1.5 mm double track fusion seams. And finally, extrusion seams made with 1.5 mm sheet were evaluated.

The test was run by first placing the mounted specimens in a constant temperature bath at 80°C for 30 minutes to reach temperature equilibrium. Next, the pre-weighed loads were carefully applied and the timers started. As each specimen failed, it tripped a switch causing the timer to stop. The time-to-failure and a description of the failure mode were recorded.

3 RESULTS

This test was shown to be an excellent way to evaluate the stress crack resistance of textured geomembranes and seams. However, the test specimen may not be the most appropriate one. Since the specimens are cut from a sheet with a steel die, the edges are deformed during the process. Therefore, it is possible that cracks that initiated on the edges of the specimens were actually started from a flaw placed in the specimen during its preparation. For this reason, it is recommended that the edges be microtomed to remove any potential flaws.

All the results reported in this paper were generated on die cut specimens. However, these results are still believed to be valid for two reasons. First, the edge failures had neither the shortest nor longest time to failure, they were mixed in with the other failures. Secondly, the residual stress found in seams is much greater than any flaws caused by the die, so seams always failed at the point of highest residual stress.

The results of the tests performed on the three sets of specimens are shown in Table 4. All the times to failure are the average of five specimens, including any edge failures in the case of the textured sheet.

Table 4 The ESCR of HDPE and COEX Samples

	ESCR (Hours)	
Sample	HDPE	COEX
Textured Sheet	390 ± 146	2018 ± 760
Double Track Fusion Seam	28 ± 3	3320 ± 553
Extrusion Seam	303 ± 291	880 ± 297

Notice that in every case the products made from COEX have greater resistance to stress cracking than those made from HDPE alone.

The samples of textured sheet evaluated were 2.0 mm in thickness and had a very thick coating applied to them. Apparently, stress crack initiation sites are created in locations where the coating adheres very well to the base sheet. It was shown previously (Thomas, 1993) that reducing the coating weight improved the stress crack resistance. Therefore, these specimens represent a worst case where many stress crack initiation sites are present.

The double track fusion seams studied were also a worse case. The seams were made under conditions that were known to leave high residual stress in the seam. Notice that the HDPE seam made under these conditions lasted only 28 hours in the test. A good fusion seam would be expected to last several hundred hours.

Figure 4 shows a microtome of the cross-section of the COEX seam before it was tested. This photomicrograph shows the outside edge of the seam where the "squeeze out" was formed. Notice that there are many crazes present that act as stress crack initiation sites. This is a very poor seam by any standards but it still lasted over 3000 hours in the stress crack test.

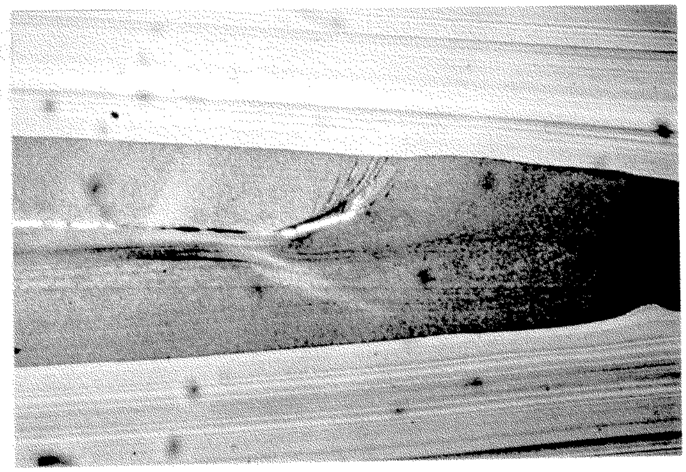

Figure 4 Photomicrograph of the COEX Seam Tested for Stress Crack Resistance (Magnification - 40X)

The extrusion seam results are interesting because of their high variability. This shows that an extrusion seam is not prepared as consistently as a fusion one. This makes sense when one considers that a fusion seam is made by a machine while an extrusion seam is made by hand.

These results showed that the VLDPE layer in a coextruded product acts as a stress reliever or a stress crack terminator which will extend the service life of polyethylene geomembranes in applications where stress cracking may occur.

4 REFERENCES

Kolbasuk, G.M. (1991) Coextruded HDPE/VLDPE Multilayer Geomembranes, *Geotextiles and Geomembranes*, 10:601-612.

Thomas, R.W. and Woods-DeSchepper, B. (1993) Stress Crack Testing of Unnotched HDPE Geomembranes and Seams, *Proceedings of the 7th GRI Seminar*, Philadelphia, 1:116-125.