Long-Term Weathering Stability and Warranty Implications for Thin Film Geomembranes

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ABSTRACT
The decision to issue warranties on a geomembrane is one that needs to balance risk with science. This paper summarizes the testing that our company performed to establish a model that could be used to evaluate warranties. Three UV testing studies were completed including a natural weathering study, a 20,000 hour accelerated testing study, and a 30,000 hour accelerated testing study. The results of these UV studies are outlined and the implications of these studies on our decision to issue warranties are discussed.

1. INTRODUCTION

Establishing warranty criteria for long-lived products used in exposed environments is always a challenge. When our company started manufacturing geomembranes in 2000 we were faced with the need to evaluate the ultra violet light (UV) stability of our geomembranes and to set warranty guidelines for those products. We were aware of long-term research that had been completed on thicker HDPE films (cite ref) and had first hand experience with coated fabric type geomembranes but were not aware of information on the extended UV stability of thin film geomembranes.

We are a specialty manufacturer of geomembranes concentrating on materials with thicknesses between 0.5 and 1.0 mm (20 to 40 mil). These thin film geomembranes are used by our fabrication facilities to produce small specialty containments in our market areas. In many cases, small size containments do not economically allow a full installation crew to perform a geomembrane installation so we have a specialized business where fabricated liners are supplied to end-users for self-installation. Our goal was to create a geomembrane that could be fabricated but that had the UV stability of thicker geomembrane materials.

Our first hand experience with coated fabric geomembranes indicated that it was possible to adequately UV stabilize thinner films. A typical 1.0 mm (40 mil) coated fabric geomembrane uses two layers of 0.4 mm (16 mil) polymeric coatings to protect an inner layer of fabric. Our experience showed that properly stabilized coated fabrics could function as exposed geomembranes for well over 20 years. We had examples of 0.75 mm to 1.14 mm (30 to 45 mil) geomembranes that had performed for more than 20 years in exposed conditions. These coated fabrics included PVC alloy materials (XR-5®) and CSPE coated materials (Hypalon®). Knowing that the UV stabilization of thin films could be accomplished, we set out to improve the stability of our thin film geomembranes to match that of 60 mil HDPE.

Our initial research showed that UV stabilization is pretty fuzzy science. Geomembranes could be installed in varieties of climate, geography, orientations to the sun, and other variables. Every time we asked the question, “how long will it last” we got the answer, “it depends.” In order to establish realistic warranty criteria we needed concrete data that would give us a realistic and conservative estimate of longevity.

2. INITIAL UV RESISTANCE STUDIES

2.1 Natural Weathering Study

In 1996, one of the authors placed a series of geomembrane samples on racks on the roof of our fabrication plant to see how a wide variety of geomembranes (and other plastic sheet samples) would react to local sunlight. These racks were oriented to face directly south and were raised to the sun at an angle of 3 V to 1 H. Our plant was located in Edmonton at 54 degrees N latitude. Since Edmonton has one of the highest levels of incident sunlight of any city in Canada this was a good choice for an initial study.

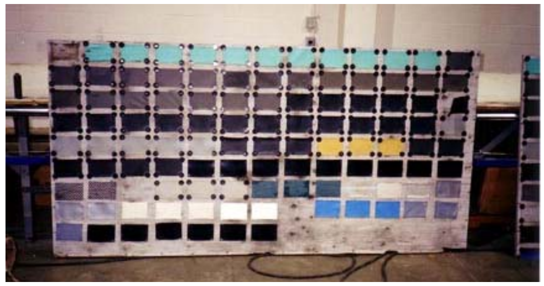

Figure 1 One of three natural weathering sample racks after 6 years of exposure.

Shortly after we began manufacturing geomembranes we saw the need to conduct a UV study. Shortly after the study was started, we retrieved the sample racks from the roof for comparison. The sample racks and their contents were used to help us relate our accelerated UV study with natural weathering data. The samples that had been exposed for six years were compared to the original specifications for the materials.

2.2 Initial Accelerated UV Study

Since an easy answer to the UV stability question was not available for our new geomembranes, we embarked on an accelerated UV testing program. We evaluated a number of accelerated UV test systems and decided to purchase a QUV/SE model fluorescent-tube accelerated UV tester from QUV. Although we reviewed a Xenon arc testing machine our testing budget did not allow consideration of the Xenon arc machine. Once the tester was obtained, we needed to determine the testing conditions. Research found that the most damaging wavelength of light for polyethylene was 300 nm and that the most damaging wavelength for PVC was 320 nm. In looking at the types of UV bulbs available we settled on UVB bulbs as the most aggressive. The second setting was the UV cycle. The equipment supplier recommended that the most aggressive settings would be an irradiance of 0.80 W/m2/nm (at 313 nm) and to include a short condensation cycle. We used these settings and an initial cycle of eight hours of UV at 60C followed by four hours of condensation at 50C.

Our initial study included many of the same materials that had been exposed in the natural weathering trial in an attempt to establish a reasonable correlation. The results of this study are contained in the paper, “UV Resistance In Thin Film Geomembranes: Accelerated and Natural Weathering Studies” (Martin, 2005) published in the proceedings of Geo-Frontiers 2005.

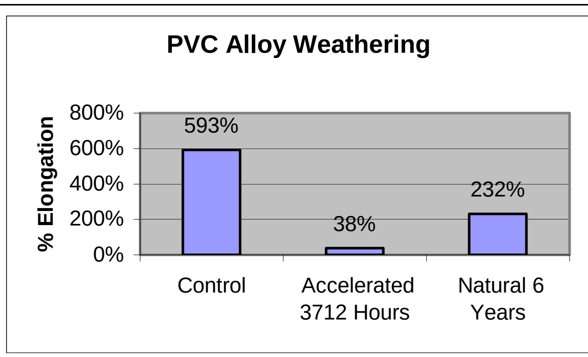

Figure 2 Comparison of PVC Alloy Elongation (Reprinted from Martin, 2005)

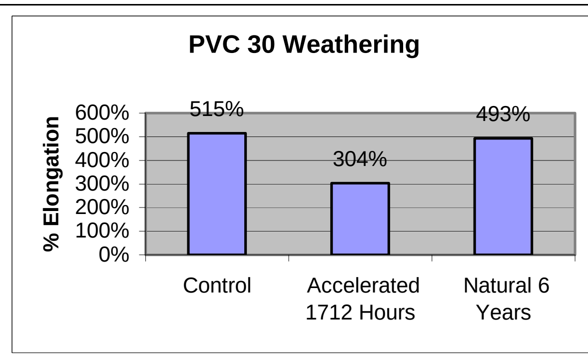

Figure 3 Comparison of PVC 30 Elongation (Reprinted from Martin, 2005)

The initial UV study looked at materials that were affected by both the natural weathering and the accelerated weathering. Figure 2 and Figure 3 show two of the PVC material types where the elongation properties had changed significantly. Neither material contained significant UV stabilizers and both materials were 0.75 mm (30 mil) unsupported film samples. Elongation in flexible materials was one of the first properties to be affected by UV degradation. The initial comparison of natural to accelerated UV testing was used to create an initial correlation.

2.3 Establishing a Correlation

A search of the literature found that an energy equivalency approach would likely suit our needs for calculating the relationship between natural and accelerated UV exposures. Since we now had examples of natural UV exposure and accelerated weathering testing we needed to establish the equivalent energy between the two tests.

From the literature (see Martin, 2005), we estimated that the total irradiance between 300 and 320 nm, which was received in a natural exposure by our geomembrane samples, could be conservatively estimated at between 4.64 and 27.9 MJ/m^2/year. Since our samples had been mounted at a 3 to 1 slope angle, this energy estimate was considered conservative. Based on the irradiance curve for fluorescent UVB bulbs (ASTM G154) and our irradiance setting of 0.80 W/m^2/nm measured at the peak emitted wavelength of 313 nm, we made an estimate of the area under the irradiance curve to determine the total irradiance between 300 and 320 nm. Based on this rough estimate, the samples in our accelerated weathering study received approximately 0.0429 MJ/m^2/hour in total energy between 300 and 320 nm.

These two calculated values gave us the following relationship:

$$\frac{4.64 \text{ to } 27.9 \text{ MJ/m}^2\text{/year}}{0.0429 \text{ MJ/m}^2\text{/hour}} = \frac{108 \text{ to } 650 \text{ Hours of Accelerated UV exposure}}{\text{Year of Natural Exposure}}$$

Our initial accelerated exposure was 16 hours per day so the values of the multipliers increase to 162 to 975 hours of accelerated testing to years of natural exposure (650 hours/year x 1.5 = 975 hours/year). Because we are attempting to establish a conservative correlation we rounded up the higher term in the relationship to 1000 hours per year of natural exposure.

When we compared this correlation number with our observed results we found that this relationship was quite conservative. Looking at Figures 2 and 3, the correlation relationship would predict that the properties of the materials would be the same after 6000 hours of exposure. Since the properties were lower after a shorter period of QUV exposure, the relationship appeared to be very conservative. A final check of the literature showed that a relationship of 1000 accelerated hours to 1 year of natural weathering was a reasonable estimation and was supported by other studies (Martin, 2005).

3. LONG-TERM UV STUDY

3.1 First Long-Term UV Study

After our success with the initial UV studies we sat down to determine what kind of testing plan would provide us with the best data for a warranty evaluation. In the literature the longest UV testing period that we found on geomembranes was 16,000 hours (Wagner and Ramsey, 2003) on HDPE. Since our goal was to match the UV performance of existing HDPE materials we established our exposure time at 20,000 hours. Since a 20,000 hour running time is 2.26 years of actual machine time, we went in to this testing knowing that it would be a long time before we had any results. With additional delays and setbacks along the way, this first long-term study took over three years to complete.

The purpose of this long-term UV study was to evaluate our new Enviro Liner® proprietary polyolefin geomembrane. In this study we included three variants of this material and one control sample of 1.5 mm HDPE. The polyolefin geomembranes were stabilized with a proprietary UV stabilization package. We established two loading levels for this package; a high and a low level. The high level was twice the loading of the low level. The study included a black and a white sample with high level UV loading and a white sample with a low UV loading. The HDPE material was obtained from our supplier at the time.

Halfway through this test, at the 10,000 hour mark, we changed the machine cycle. We increased the UV exposure time from an 8 hour UV exposure and 4 hour condensation cycle to a 10 hour UV and 2 hour condensation cycle. This was done to make the conditions more aggressive and to make our correlation between accelerated UV testing and natural testing more conservative.

Sufficient specimens were included in the study so that we could perform intermediate testing. Tests were performed at 2000; 6000; 10,000 and 20,000 hours (tensile tests at break, method appropriate to the material, see Martin 2005 for details). The results are plotted in Figure 4. See the previous paper (Martin 2005) for a more complete description of this testing.

The results of this first long-term UV study were very encouraging. We learned that we could stabilize a 0.75 mm (30 mil) polyolefin geomembrane to match the performance of a standard HDPE 1.5 mm (60 mil) material. With a high loading of the UV additive we could even stabilize a white material to give similar performance. Our conclusions from this first study were that we could conservatively expect our 0.75 mm (30 mil) stabilized geomembrane to retain over 80% of its properties after 20 years of exposed service.

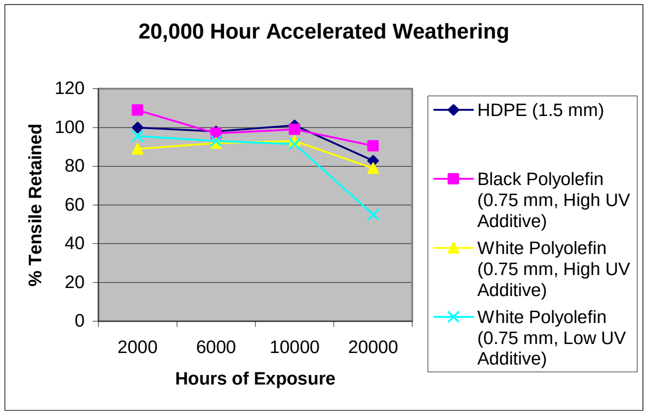

Figure 4 First Long-Term UV Test Results
(Reprinted from Martin, 2005)

4. WARRANTY IMPLICATIONS

4.1 Relating UV Testing to Real Life

With the first long-term UV study in hand we set out to evaluate a level of acceptable warranty risk. On the one hand, our UV study had shown that our stabilized polyolefin geomembrane had performed as well or better than a similar sample of HDPE. On the other hand, we needed confidence that the 20,000 hour performance of the HDPE could be related to a real life exposure. In order to convince senior management that the risk was acceptable we needed to connect real life HDPE exposures to our accelerated weathering testing.

Fortunately we had been monitoring one of our first HDPE installations. As described in the paper by Mills (1998) samples had been removed from a 1987 HDPE installation and tested. The results of that testing had shown that the HDPE was holding up well and should easily last 20 years. Additional maintenance visits in 2002 and 2007 showed that this early type of HDPE has easily stood up to 20 years of service. Measurements of the anti-oxidant level (OIT testing) have shown that the antioxidant is mostly depleted; however, the tensile strength of the material is still holding up at 20 years. Having this real life example to make comparisons with was an important input to our evaluation of warranty risk.

4.2 What Risk is Acceptable?

At this point we had a quantity of test data that gave us some confidence that our material would easily last for 20 years in an exposed condition in our region. We felt that our data was conservative since we had purposely chosen the most conservative values throughout our evaluation. The next step was to evaluate the level of risk.

The most common type of warranty in the geomembrane market is a straight line warranty. In this type of warranty the value decreases by 1/period each year until you reach the end of the period. There is also another type of warranty that is used by at least one geomembrane manufacturer where the retained value is multiplied by a factor for each year in the period (Year A Value x Factor = Year B Value; Year B Value x factor = Year C Value; etc.). This declining balance type of warranty does not reach a zero value at the end of the term. These two types of warranty are illustrated in Figure 5.

Since this is an evaluation of risk, the key is to look at the retained value near the end of the warranty term. In the case of a 20-year straight line warranty, the retained value of a $100,000 geomembrane at year 19 is $5,000. By way of comparison when we set the factor in the declining balance warranty to 0.86 we were able to duplicate a retained value of $5,000 at year 19. Comparing these two types of warranty in Figure 5 shows that the declining balance type presents the least risk to the geomembrane manufacturer but that the straight line warranty provides the most protection to the project owner.

It takes a remarkable amount of discussion to establish an extended warranty program in a company that has not previously issued product warranties. That discussion is especially difficult when the term of the warranty is significantly higher than the current warranties available in the market place. The longest warranty term available at the time for unsupported thin film geomembranes was a 5-year straight line type. We were proposing a 20-year warranty. The issue of the warranty type was settled in favor of the type most advantageous to the customer. We chose the straight line warranty as being more common in the industry and of most advantage to our customers. Our goal was to set the standard of 20-year warranties on 0.75 mm (30 mil) geomembranes and after much discussion we achieved that goal. Our company now provides 20-year straight line warranties to our customers.

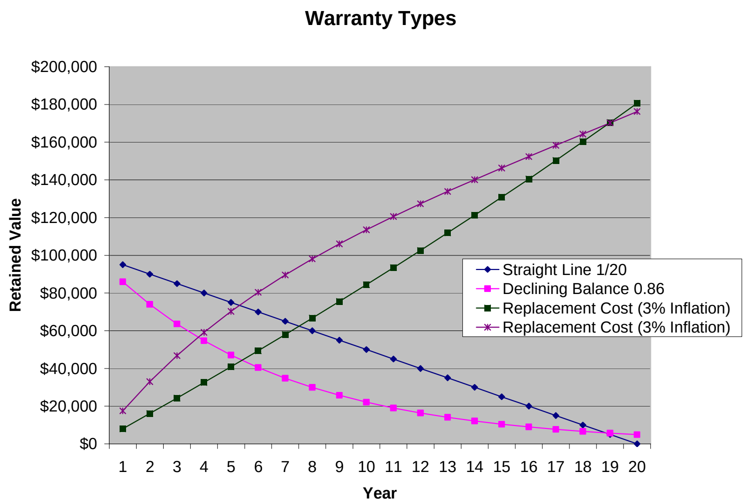

Figure 5 Possible warranties applied to a $100,000 Geomembrane showing replacement costs

5. SECOND UV STUDY

5.1 Confirmation of Production Material Properties

Some people will have noticed in the discussion to this point that in the first long-term UV study we had not tested our black polyolefin geomembrane with the lower UV loading level. This was a result of problems during sample preparation and was identified early on as a deficiency of the first extended UV test. The first samples had been prepared on lab equipment since we had not yet started full geomembrane production. During that first UV study we added additional samples as they became available. The paper on the first long-term study (Martin 2007) was published before these production samples were tested at the 20,000 hour mark.

By the time the first long-term UV test had reached the 10,000 hour mark, our production of geomembrane was well established. We added production samples of our black polyolefin geomembrane to the UV tester with the low level of UV additive with the specific intention of testing that formulation at 20,000 hours. A second control sample of HDPE was also added to the UV tester to match the exposure of this specific sample. This second long-term UV test then, was to confirm that our black 0.75 mm (30 mil) polyolefin geomembrane with the lower level of UV stabilizer, would provide equivalent performance to 1.5 mm (60 mil) HDPE.

Since this particular test was being carried out at the same time as the first UV test (offset by 10,000 hours) the first results were available for our discussion on warranties. For example, the 20,000 hour portion of this test was completed before the final decision was made on warranties. Having the results from this production sample allowed us to establish our warranties based on actual production material with an economical loading of the UV stabilizer.

5.2 Moving the Goal Posts Again

So, with warranties in place, and 20,000 hour UV testing completed on production samples, we were prepared to wrap up our UV testing. But we still had three specimens of each material in the weather tester. We decided at this point to push the UV testing out to 30,000 hours. This additional exposure would solidify our decision on 20-year warranties, allow us to make reasonable warranty decisions in regions with higher incident sunlight, and would allow us to consider extending warranties beyond 20 years.

This extended long term UV test tested a sample of our 0.75 mm (30 mil) black polyolefin material and a 1.5 mm (60 mil) HDPE material out to 30,000 hours. The exposure for these samples was 10 hours of UV light at 60C followed by a 2 hour condensation cycle at 50C. UVB bulbs were used with an irradiance of 0.80 W/m2/nm (at 313 nm). This exposure level was set when these samples were added to the weather tester and were not changed over the period of this test.

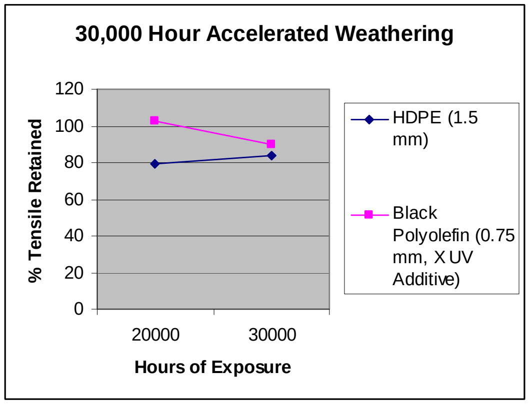

Figure 6 Tensile Results from 30,000 UV Test

The samples were tested for retained tensile strength. The 0.75 mm (30 mil) black polyolefin geomembrane was tested according to ASTM D882 using 6 mm (0.25") wide specimens. Using this small specimen size allowed us to cut 15 test coupons from the exposed area of the sample. Identical test coupons were cut from the same relative location on retained samples for comparison. The HDPE tensile samples were cut with an ASTM D638 type VI die. This die is smaller than what is used in normal HDPE tensile testing but allowed us to cut 10 test coupons out of the exposed sample. The same size test coupons were cut from the same relative location on a retained sample. Figure 6 summarizes the tensile test results. The HDPE maintained about 80% strength retained at both 20,000 and 30,000 hours. The 0.75 mm (30 mil) polyolefin sample retained 100% at 20,000 hours and 90% at 30,000 hours.

Another key indicator of longevity is the retained stabilizer content of the polymer. We measured the content of anti-oxidant stabilizers in the samples using the HP OIT test (ASTM D5885). We compared the stabilizer content in the sample after 30,000 hours of exposure with the content measured in the retained sample. The 1.5 mm (60 mil) HDPE retained 44% of its HP OIT value while the 0.75 mm (30 mil) polyolefin retained 69% of its original HP OIT value. Figure 7 illustrates this result. The GRI-GM13 specification for HDPE specifies an HPOIT value of 400 minutes for new material so this sample is still very close to specification after 30,000 hours. You can see by these results that the 0.75 mm (30 mil) polyolefin material is highly stabilized and is retaining its properties very well at 30,000 hours of exposure.

HP OIT Results	Retained Sample	30,000 Hour Sample	% Retained
0.75 mm Black Polyolefin	4410 min	3056 min	69%
1.5 mm HDPE	899 min	396 min	44%

Figure 7 HPOIT Retained Values

6. WARRANTY IMPLICATIONS 2

The implications of the 30,000 hour test on our warranties are important. First of all, the purpose of all this testing was to give us confidence in the longevity of our product so that we could establish industry-leading warranties. We are now comfortable with our results and are able to offer a 20-year straight line warranty in most regions. We also have sufficient information now to evaluate warranties in regions with more intense UV exposure. We recognize that our initial relationship between accelerated UV testing and natural exposure was done at temperate latitudes. By taking the testing to the extreme of 30,000 hours we have a better guideline to help us make reasoned choices about whether to provide a warranty in higher UV locations.

Finally, we are beginning the discussions about whether we can extend our warranties even further than 20 years. The data from this latest test seems to support a longer warranty term. What we have to decide is whether a warranty longer than 20 years is in the interests of our company, whether it will provide commercial advantage, and whether setting a standard warranty on this product will have an adverse affect on other products. Those discussions are just beginning.

7. CONCLUSION

The decision to issue product warranties on geomembranes is a difficult decision for a company. The best way to approach that decision is to test the product in a way that most closely replicates conditions of use and then make a conservative estimation of how your testing and actual use will compare. Over the past number of years we have taken UV testing on our material far beyond normal industry practice and have obtained excellent results. That testing has influenced our decisions regarding warranties and continues to shape how we apply our product to our customer's applications.

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