Thirty Year Old Performance of PVC Liners in the Aquacultural Industry

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In 1971 twenty circular aquaculture ponds were constructed at the W.K. Kellogg Biological Research Station at the Michigan State University facility in Hickory Corners, Michigan under a grant from the National Science Foundation. Eighteen of the ponds are for experimental purposes and are two are for storage purposes (see Figure 1). The ponds were allowed to colonize naturally with flora and fauna from surrounding lakes, and within a few years the experimental ponds closely resembled natural systems. These conditions provided the opportunity to conduct a number of significant experiments on species interactions and habitat selection in fishes. Additional information on the W.K. Kellogg Biological Research Station can be found at their website: http://www.kbs.msu.edu/Research_Facilities/Pond_Lab/Overview.htm

The one-hundred foot diameter research ponds were lined using 20 mil thick fish grade PVC geomembrane. A fish grade PVC geomembrane is specially formulated to promote aquatic life through the omission of biocides from the basic PVC geomembrane formulation that can leach out over time. The basic formulation of a PVC geomembrane corresponds to 60-65 % PVC resin, 32-38% plasticizer, 5-8% stabilizers and additives, and 0.5-1% pigment (Diebel 2000). The ponds are eight feet deep with sideslopes of three horizontal to one vertical. After installation, each PVC geomembrane was covered with one foot of sandy soil cover.

Over the years the ponds became congested with dense, persistent stands of cattails and other vegetation (see Figure 2). These conditions made many types of experiments impossible and thus to start new aquaculture experiments, nine of the ponds were cleared and re-lined in September 2000. This provided a unique opportunity to exhume nearly thirty-year-old PVC geomembranes and evaluate their engineering properties. It is important to note that NONE of the ponds were leaking nor exhibiting any problems during the thirty years of service. The nine ponds were re-lined with 20 mil PVC fish grade geomembrane liner fabricated in circular panels. Each panel is of 11,060 square feet and comprised of Geon, Incorporated of Burlington, New Jersey material from lot number 43464. The circular panels were fabricated by Environmental Protection, Inc. and Woolf Excavating of Kalamazoo, MI installed the one-piece liners in ponds 4 through 8, 10, 16, 17, and 18.

On September 13, 2000, a representative from the University of Illinois at Urbana-Champaign removed samples of 30-year old 20 mil PVC geomembrane from the ponds. The samples were exhumed from three main locations: (1) from the side slopes above the water line, (2) from the side slopes below water line under the omnipresent cattails, and (3) from the bottom of the pond. The samples were sealed in large plastic bags to minimize moisture loss prior to testing and driven to Urbana-Champaign. Some of the samples were then shipped to TRI/Environmental in Austin, Texas for comparison testing.

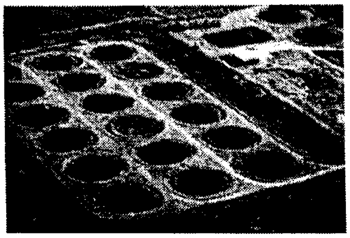

Figure 1. Twenty ponds constructed in 1971

Figure 2. Willow tree and cattails being removed to exhume the PVC Geomembrane

Observations of Geomembrane During Excavation

All of the samples removed from the pond were soft and flexible. The flexibility of the thirty year old material is illustrated in Figure 3 by the photographs of a specimen of the sideslope material before and during tensile testing. Material removed from the bottom of the pond was softer to the hand than the material from above the water line. Once the samples were desiccated, the samples were somewhat less flexible, which strongly suggests that the material should be tested in the insitu condition, i.e., without desiccation, to assess the insitu properties.

At the center of each pond an inletloutlet structure was constructed (see Fig 4). This structure consisted of a concrete slab, approximately 2.5 feet x 2.5 feet, with the top level with the liner subgrade. The liner was placed over the concrete, sealed with butyl mastic, and fastened to the concrete using 2" x 4" redwood batten strips and concrete nails. This structure and the batten performed well over the thirty years as indicated by no discoloration of the soil under the PVC geomembrane and around the structure. These observations also indicate that there was little, if any, leakage through the liner in the vicinity of the inletloutlet structure. In addition, the mastic was soft and flexible after 30 years, which resulted in an effective seal around the nails.

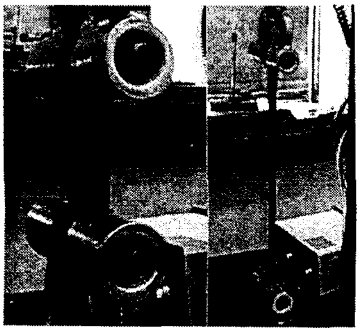

Figure 3. Exhumed PVC geomembrane before and during tensile testing

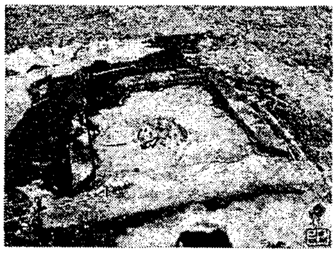

Figure 4. Redwood strips surrounding the inlet/outlet structure at bottom of pond

Root Penetration and Microorganisms

One of the most important aspects of this forensic study was the effect of root penetration and microorganisms on the PVC geomembranes. As mentioned previously, the pond was overgrown with vegetation, which prompted the excavation and pond re-lining. Each of the ponds had a large amount of cattails around the perimeter of the pond (see Figure 2) and in the middle of the pond (see Fig. 5). As the bulldozer removed the soil from the top of the geomembrane under the cattail area, observations were made of the root zone of the cattails. These cattails produced one root stalk about 3/4" to 1-1/4" in diameter, with a mass of smaller roots around the main root. The root length was approximately 1 to 3 feet. All roots of the cattails grew down to the PVC geomembrane and then grew horizontally along the top surface of the geomembrane. No evidence of roots penetrating the geomembranes was found during field inspection and after holding the geomembrane over a light source.

One of the ponds in which the liner was exhumed there was a small willow tree growing about five feet down slope of the anchor trench but above the water level. The willow tree was 12 to 15 feet tall and had a trunk of 6-8 inches diameter (see Figure 2). As the bulldozer operator cleared the dirt from the sides of the tree, it was observed that the large tree roots also grew down to the geomembrane, then turned and traveled along the surface of the geomembrane. The main tree roots were 3-5 feet long, with some smaller roots extending up to 7 feet from the tree trunk. When the dozer pushed the tree over, it slid down the geomembrane to the bottom of the pond, leaving the geomembrane intact after nearly thirty years. Again no evidence of root penetration was found during field inspection and after holding the geomembrane from the vicinity of the willow tree over a light source. These observations are especially significant because the geomembrane is only 20 mil thick.

The lack of observing holes in the field and the laboratory also suggests that the geomembrane not only resisted root penetration but also biological attack from microorganisms. This is significant because the experiments conducted in the ponds introduced many types of microorganisms inside and outside of the ponds. This qualitative data suggests that there has been no detrimental effect on the geomembrane from root penetration or microorganisms in this harsh environment since 1971.

Test Results on Exhumed Geomembrane

Samples exhumed from above and below the water line were tested at the University of Illinois at Urbana-Champaign (UIUC) to evaluate the effect of submergence. Only samples exhumed from below the water line were tested at TRI/Environmental. Samples from each location were tested in both the Machine (MD) and Transverse (TD) directions. The test results are compared to the PVC Geomembrane Institute (PGI) specification (PGI 1197) for the material properties and seaming requirements of PVC geomembranes effective January 1, 1997. The PVC Geomembrane Institute (PGI) developed the specification to eliminate the void left by the obsolescence of the National Sanitation Foundation specification (NSF-54) for the material properties and seaming requirements of PVC geomembranes. This comparison is to illustrate that the exhumed material still exceeds the PGI-1197 specification after nearly thirty years. The specification is used for comparison purposes because pieces of the original material were unavailable for testing after nearly thirty years. The samples from each location reported on herein were cleaned and allowed to acclimate in the lab for 40 hours according to the applicable ASTM standard test methods. Additional samples were tested from each location without any desiccation. These results are being reported in a technical paper due to space constraints, and yield more favorable results than the desiccated samples described herein because they simulate the field moisture condition, which results in a more flexible material. As a result, the desiccated test results presented herein present a worst case scenario for the insitu material. Even though desiccated samples were used it will be shown that the geomembrane still exceeds the requirements of the PGI-1197 specification.

Review of Table 1 shows agreement between the test results obtained from the testing at the UIUC and TRI/Environmental. More importantly, the nearly thirty-year-old material properties exceed the PGI-1197 required values. The data shows a sufficient percent elongation at break (greater than 350%), which indicates that the material retained flexibility even after thirty years. Samples were also tested to determine the secant modulus of elasticity, a measure of stiffness or extensibility, which is calculated using the load required to achieve 100% strain.

This test indicates the strength of the material is when it is under stress. The secant modulus was approximately two times higher than the recommended values which indicates some hardening over thirty years. A low secant modulus indicates a softer, more elastic/flexible material, while a high modulus number indicates a stronger, stiffer material. If the PVC geomembrane exceeds the recommended value of 23 pounds/inch width of specimen (see Table 1), this indicates that the formulation was proper and the plasticizer was sufficiently retained in the aquatic environment and the thin geomembrane (20 mil). Plasticizer retention is more difficult in an aquatic environment because as the water circulates, it is harder for the geomembrane to retain the plasticizer. The material tested in Table 1 was obtained from near the bottom of the pond. In addition, the thinner the sheet, the larger the impact of surficial plasticizer loss will be on the measured properties. Therefore, the test results on a 20-mil thick PVC geomembrane after nearly thirty years in an aquatic environment exceeding the PGI-1197 recommended values is significant. In non-aquatic environments it has been shown that plasticizer retention is higher than in aquatic environments, e.g., see data in Table 2, so the use of a PVC geomembrane in a waste containment cover system application should experience even greater plasticizer retention.

Table I: Material exhumed from below the water level and specimens desiccated in accordance with corresponding ASTM Standard Test Method

TEST	**Orientation**	**PGI - 1197**	UIUC	**TRI**	**Test Method**
Tensile Properties *(Break Strength, lbs/inch)*	MD	48	71.8	62	ASTM D882, Method A
	TD	48	58.5	60	
Tensile Properties *(Elongation at Break, %)*	MD	350	352	368	
	TD	350	355	447	
Tensile Properties *(Secant Modulus at 100% Strain, lbs/inch)*	MD	23	55.8	Not Tested	
	TD	23	49.2	Not Tested	
Tear Resistance *(lbs.)* (tensile strength with a notched specimen)	MD	6.5	13.3	8.4	ASTM D1004, Die C
	TD	6.5	12.1	8.2	
Seam Properties *(Bonded Shear Strength., lbs/inch)*		38.4	51.8	Not Tested	ASTM D882

Hydrostatic Resistance *(psi)* (measures flexibility and burst pressure)		68	149.3	103	ASTM D751 (A)
Thickness *(minimum, mils)*		19	18.9	20.5	ASTM D5199, ASTM D1593
Dimensional Stability *(% change)* (Illustrates difference between MD and TD which may indicate change in manufacturing)	MD	±5	-4.70	-2.02	ASTM D 1790 (100C, 0.25 hr)
	TD	±5	-1.37	0.87	
Water Extraction (% *change)* (measures plasticizer retention in water)		-0.15	0.90	.04	ASTM D 3080
Volatile Loss (% *loss)* (measures plasticizer retention in activated carbon)		0.9	0.01	0.26	ASTM D 1203
Low Temperature Brittleness *(%passing at -26C)* (Determines temperature at which geomembrane exhibits brittle failure under a given impact condition – which indicates plasticizer effectiveness)		80	90	100	ASTM D 1790

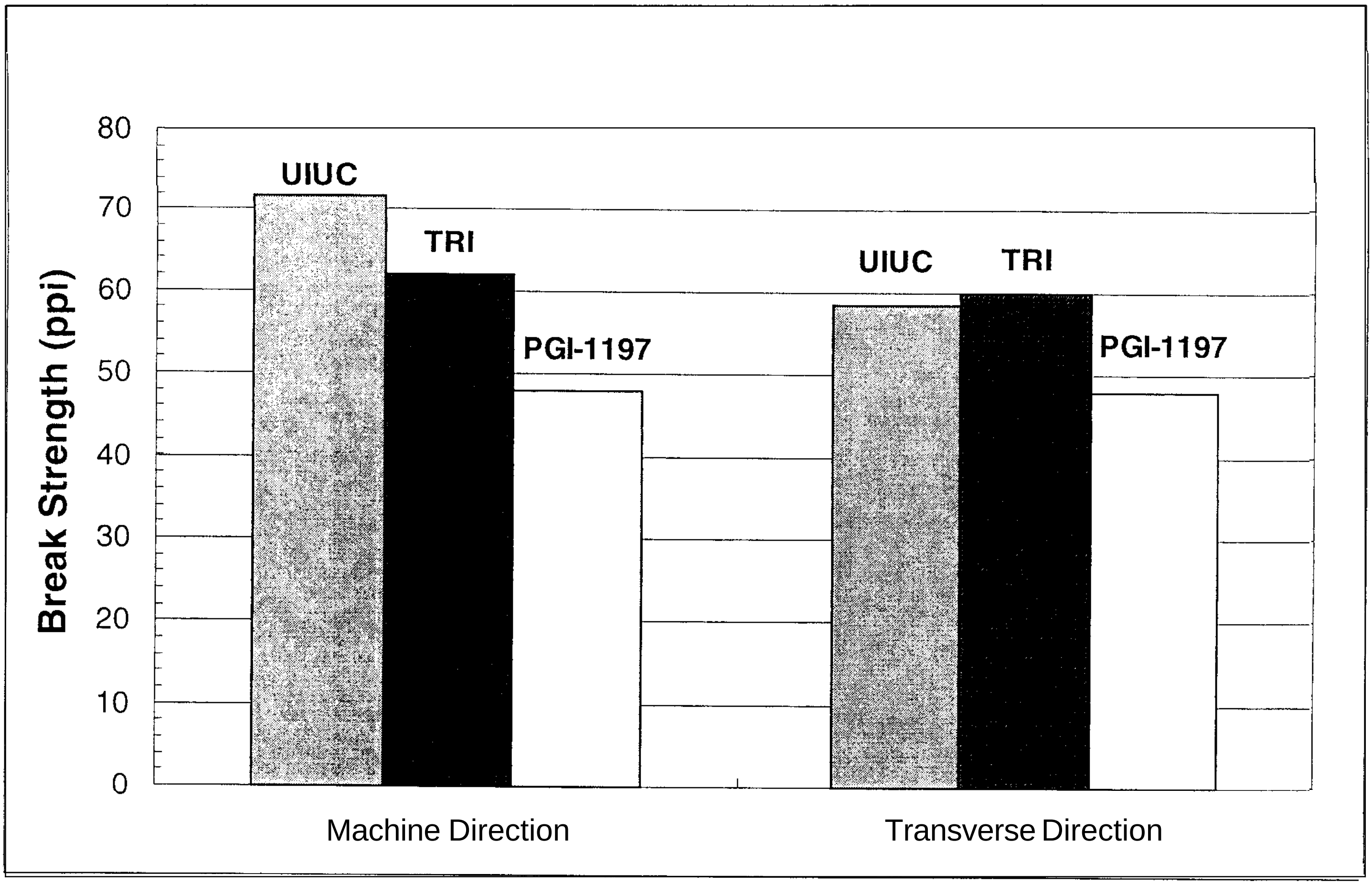

Figure 6: Tensile Break Strengths in the machine and transverse directions compared to the PGI-1197 specification

The tear resistance also exceeded the PGI-1197 recommended values. The factory seams were created using a solvent and the performance of the seam over thirty years was of interest. It can be seen from Table 1 that the bonded shear strength also exceeded the recommended values. TRI/Environmental did not test a seam because the material that was shipped did not contain a seam. One interesting result from the testing is the water extraction data. The UIUC data indicates a gain in water during the test as did the TRI/Environmental albeit to a lesser degree. This may be attributed to the desiccation prior to testing.

Table 2 presents the test results on the PVC geomembrane exhumed from above the water line. Therefore, the geomembrane was not subject to a constant aquatic environment and thus was expected to retain more plasticizer. Evidence of greater plasticizer retention can be seen in comparing the tensile properties in Tables 1 and 2. The break strength is lower for the material above the water line indicating a softer material than below the water line. This additional plasticizer retention above the water line is also reflected in the larger value of percent elongation at break and lower values of secant modulus. As in Table 1, the water extraction data showed a gain in water during the test. In summary, the data in Table 2 shows there is greater plasticizer retention in non-aquatic environments, such as landfill cover systems, which results in a greater retention of flexibility even after nearly thirty years.

Table 2: Material exhumed from above the water level and specimens desiccated in accordance with the corresponding ASTM Standard Test Method

TEST	Orientation	PGI 1197	UIUC	Test Method
Tensile Properties *(Break Strength, lbs/inch)*	MD	48	60.2	ASTM D882, Method A
	TD	48	56.5	
Tensile Properties *(Elongation at Break, %)*	MD	350	369	
	TD	350	351	
Tensile Properties *(Secant Modulus at 100% Strain, lbs/inch)*	MD	23	48.2	
	TD	23	47.2	
Tear Resistance *(lbs.)*	MD	6.5	11.3	ASTM D1004, Die C
	TD	6.5	10.6	
Seam Properties *(Bonded Shear Strength, lbs/inch)*		38.4	49.0	ASTM D882

Hydrostatic Resistance *(psi)*		68	149.9	ASTM D751 (A)
Thickness *(minimum, mils)*		19	18.7	ASTM D5199, ASTM D1593
Dimensional Stability (% *change)*	MD		-4.12	ASTM D 1790 (100C, 0.25 *hr)*
	TD	±5	-3.69	
Water Extraction (% *change)*		-0.15	1.00	ASTM D 3080
Volatile Loss (% *loss)*		0.9	0.11	ASTM D 1203
Low Temperature Brittleness *(%passing at -26C)*		80	89	ASTM D 1790

Summary

After 30 years of service, this 20 mil PVC geomembrane retained its flexibility and strength enabling it to perform as a successful water barrier. This clearly indicates that plasticizer retention is not a problem even with 20 mil thick material. These results are significant because they support the use of PVC geomembranes in aquatic applications and more importantly bolster the application of PVC geomembranes in non-aquatic environments because the plasticizer retention will be greater in a non-aquatic environment as shown by the data herein. This case history also dispels some myths that PVC geomembrane material and/or seams can be compromised or deteriorated by root penetration or microorganisms, respectively. The roots and microorganisms did not penetrate the 20 mil thick material and thus the likelihood of roots and microorganisms affecting thicker material is less.

References

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