Long-Term Performance of PVC Geomembranes in the Mining Industry

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INTRODUCTION

Polyvinyl Chloride (PVC) geomembrane liners have been used in the mining industry since the early 1970's, and in particular for the containment of process solutions in gold, silver and copper ore heap leaching operations from 1979 to the present day. The ore heap leach fills are some of the highest and heaviest loaded geomembrane lined fill structures in the world, consisting of crushed rock fill materials placed in controlled lifts for leaching with alkaline or acidic process solutions. The ore heap fills require stable slope conditions and long-term performance of the underlying buried geomembrane liner system to prevent leakage of process solutions to the natural foundation subgrade and ground water.

This article presents an overview of the long-term performance of PVC liners in the mining industry, based on personal observations and test studies conducted on liner systems from several ore heap leach projects in North and South America. The discussions focus in particular on a gold ore heap leach pad constructed in the 1980's with PVC liners made by several manufacturers. The buried PVC liners were randomly excavated and sampled from the leach pad for testing 5 to 9 years after installation and exposure to harsh heap leach chemicals and operations. The test results indicate that the buried PVC liner materials performed extremely well over long periods of time beneath the ore heap fills. This is in agreement with many other installations of PVC geomembranes in the mining industry (Diebel 2000).

BACKGROUND

General

PVC geomembranes were the first type of geomembrane liner system used in the mining industry, starting in 1970 with solar evaporation brine ponds in Utah, followed in 1979 by gold and silver heap leach operations in western Montana and southern California. By the end of the 1980's, PVC liners were being used as a composite liner system beneath heap leach pads for mining projects in Alaska, Arizona, California, Colorado, Montana, Nevada, Utah, Washington, and Northern Mexico. By the end of the 1990's, PVC liners were being used on international mining projects extending from North America to South America, Australia, and Africa. The flexible PVC liners are generally selected for mining operations, based on lower costs to fabricate, ship, deploy, and seam the liners at remote sites, and the excellent PVC engineering characteristics related to puncture resistance and high interface friction strengths.

This section describes a typical heap leach operation and the sequence of personal observations and engineering field and laboratory studies related to the long-term performance of PVC geomembranes in the mining industry. These experiences and test studies may also be applicable to other types of containment fill structures such as landfills and cover fill caps.

Heap Leach Operations

Gold, silver and copper ore heap fill structures generally have existing or planned vertical fill heights in the range of 100 to 200 feet (30.5 to 61 meters). Some of the highest heap fills exceed 300 feet (91.4 meters) in vertical height, especially at the copper mine sites. The maximum current known fill height on a geomembrane liner system is about 500 feet (152.4 meters) on 30 and 40 mil (0.75 and 1.0 mm) thick PVC geomembranes at a gold mine site in Montana.

The construction of heap fills involves placement of precious or base metal ore materials in controlled loose fill lifts stacked at the natural angle-of-repose above a geomembrane lined leach pad. Each ore lift surface is uniformly wetted by irrigation drip emitters or sprinklers for leaching with alkaline (gold and silver) or acidic (copper) process solutions. The maximum rock particle size of the granular ore materials range from run-of-mine cobble and boulder rock sizes to crushed sand and gravel sizes. The individual ore lifts are offset with benches along the exterior slope as required for slope stability. Photo 1 shows an existing heap leach fill stack with the described benches in the background with construction subgrade preparation for a new leach pad in the foreground.

Field Test Fill Study in 1989

A geomembrane liner field test study was conducted in 1989 at a copper mine site in southern Arizona on 30 and 40 mil (0.75 and 1.0 mm) thick PVC and 60 mil (1.5 mm) thick non-textured HDPE (high density polyethylene) liner materials. Textured HDPE liners were experimental at that time. The PVC liner test sheets were provided by Watersaver Company (Denver, Colorado) and PALCO (Stanton, California). The HDPE liner test sheets were provided by Poly America, (Grand Prairie Texas). The primary purpose of the study was to compare the durability of the various liner materials and sheet thickness under heavy cover fill traffic loads for selection of an optimum copper heap leach liner system (Breitenbach, 1992). Photo 2 shows the field test site and a copper ore stockpile in the background.

The geomembrane liner sheets were placed side by side on a smoothed and compacted fine grained bedding fill and covered by minus 0.75 inch (19 mm) sand and gravel drain fill in a 24 inch (600 mm) thick loose lift. Photos 3 and 4 show a dump truck placing the drain cover fill in piles over the geomembrane liner test sheets for spreading by a rubber-tired dozer.

After the drain cover was leveled by the dozer, the PVC liner test sheets were subjected to several passes by a loaded rock truck to simulate planned traffic on the leach pad liner system. Photo 5 shows a loaded rock truck on the liner test pad with wood stakes marking the different liner test sheets beneath the cover drain fill.

After 10 passes by the loaded rock truck, the loose lift compacted down to an approximate 18 inch (450 mm) lift thickness above the PVC liners. Hand excavations were periodically conducted within the footprint of the tire tracks to expose and observe the performance of each liner after 10, 20 and 40 truck passes. Photo 6 shows a hand excavated hole to observe the condition of the buried liner after 10 rock truck passes. Photo 7 shows a hand excavated trench to expose and observe all of the liner test sheets after 40 truck passes.

The geomembrane liner field test fill study showed that the PVC liner withstood significant dynamic rock truck traffic loads without liner sheet damage, material sliding, or rock puncture. The non-textured HDPE liner also did not puncture, but showed scratch damage from drain rock fragment movement on the top liner surface. The difference in rock movement along the PVC and HDPE materials is attributed to the difference in the interface strengths between smooth HDPE and PVC geomembranes. Stark and Richardson (2000) showed that the interface strength of a PVC geomembrane is significantly higher than a smooth HDPE geomembrane because of the flexibility and/or pliability of the PVC geomembrane (Hillman and Stark, 2001).

Laboratory Direct Shear Tests in 1990

The site observations of heap leach pad liner construction and field test fill studies on various liners indicated that the more flexible geomembrane liners should have the highest friction strength at the liner to soil interface contact. However, the laboratory test strength information obtained from geosynthetic liner conferences and published books in the 1980's did not support the field observations and construction experience. The published test strengths generally showed no significant difference between the more rigid non-textured HDPE liner sheets and the more flexible LDPE (low density polyethylene) and PVC liner sheets. The reliability of laboratory test strength values was examined in 1990, first by conducting independent laboratory verification tests on the same test materials, and second by studying the affect of a rigid versus a flexible liner interface surface as discussed below.

A laboratory test verification study was performed on liner interface strengths in 1990, while consulting with an engineering firm in Colorado. Identical composite liner samples of 60 mil (1.5 mm) non-textured HDPE geomembrane liner sheets, underliner bedding fill and overliner drain cover fill materials were sent to three separate and independent laboratory test facilities in Georgia, Texas and California. The strength tests were conducted with the small 4 inch (100 mm) direct shear box test apparatus (commonly used throughout the 1980's for liner strength testing) under the same sample preparation and load test conditions. The peak interface friction strength test results from this study showed a significant variation in liner interface strengths for the same liner test materials, i.e., friction angles of 19.8, 24.0 and 30.4 degrees. This data shows a maximum difference of 10 degrees, i.e., 33 to 50%, between the highest and lowest peak strength test values.

The published literature on liner strengths generally did not include the important background test factors for referencing or selecting the appropriate liner interface strength parameters for use in stability analyses. The important composite soil factors include the overlying or underlying soil gradations, maximum rock particle size, plasticity, moisture conditions, consolidation loads, rate of shear strains, or time of loading before shear testing. The composite geomembrane factors include the liner type, thickness, surface texture, and flexibility, which adds more variables to the composite liner test results.

The liner flexibility appeared to have the most influence on liner interface strengths, based on construction observations of liner installation, drain cover fill placement, and subsequent high stack ore lift placement operations on the leach pad liner systems. In particular, the sliding friction grab strength of PVC liner sheets was significantly higher than for HDPE liner sheets, when pulled by liner crews across the compacted subgrade surface during deployment and seaming. This is in agreement with the higher interface strength observed and measured for a PVC geomembrane than a smooth HDPE liner. Large rock particles could be pushed by hand across the HDPE liner surface, but not across a PVC liner surface. The construction observations indicated that there should be a significant interface friction strength difference between the more flexible versus more rigid liners. To determine the relative difference in strength between the flexible and rigid liners, a laboratory test study was conducted in 1990 for a gold heap leach project in Idaho and for a subsequent copper heap leach project in Arizona. In each laboratory test study the PVC liner sheets were glued to wood blocks in a large 12 inch (300 mm) direct shear box to test the strength of the worst case rigid and planar subgrade conditions.

The first test for the Idaho project compared a 40 mil (1.0 mm) thick PVC liner sheet to a 1.5 mm non-textured HDPE liner sheet with both sheets glued to a wood block as a rigid underliner subgrade. The liners were then covered with overliner drain fill, wetted, loaded and consolidated to high equivalent fill load conditions for testing the drain fill to rigid liner interface surface. The relatively rigid wood block subgrade surface prevented the liners from "dimpling" to a micro scale non-planar surface. The HDPE test results showed a peak interface friction angle of 18 degrees. The PVC test results showed a peak interface friction angle of 22 degrees. The test results with the rigid wood block subgrade show the PVC liner has a higher interface friction value compared to the HDPE liner, which agrees with construction installation and test study observations.

The second test for the Arizona project compared a "rigid" 40 mil (1.0 mm) PVC liner with glued wood block subgrade to a flexible PVC liner in contact with a composite low permeability clayey soil and overliner sand drain fill. The test results showed the "rigid" PVC to clayey soil with a peak interface friciton angle of 2 degrees. The flexible PVC to clayey soil peak interface friction angle was 25 degrees and no apparent cohesion. The test results show that the flexible PVC liner gains strength from apparent micro scale dimpling of the interface surface. This data is also in agreement with the data presented by Stark and Richardson (2000).

PVC Liner Exposure From 1983 to 1993

A gold and silver ore heap leach pad was constructed in Colorado with 30 mil (0.75 mm) thick PVC liner at about Elevation 10,500 feet (3,200 meters) in 1983 to 1985 and operated for about 5 years. The leach pad liner was covered with ore fill materials and the exterior liner anchor trench limits remained exposed to sunlight, extreme temperature fluctuations, freeze-thaw action and high winds. A drainage ditch was being added to the edge of the leach pad in 1993, which exposed some of the PVC pad liner that had been buried for 8 to 10 years.

The buried PVC liner was observed to be flexible with no apparent damage or visual change in the liner sheet material since the time of installation. However, the exterior liner anchor trench sheet that remained exposed to sunlight for 8 to 10 years was brittle and showed loss of flexibility due to the high mountain climatic conditions. No testing was performed on the leach pad PVC liner sheets to assess the actual condition of the buried and exposed liner materials.

CASE STUDY IN 1994

General

Several gold heap leach pads were constructed adjacent to each other in Southern California from 1985 through 1989 using a composite soil and 40 mil (1.0 mm) PVC liner system. The fabricators and installers for the various phases of the leach pad construction included Environmental Liners, Inc. (Cortez, Colorado), PALCO Linings, Inc. and Watersaver Company, Inc. The PVC liners were covered with 12 to16 ounce per square yard geofabric and drain fill material for placement of ore in controlled lifts to maximum vertical heap fill heights of 120 feet (36.6 meters).

This section discusses liner sample selection, index testing, and liner test results conducted on representative samples of the existing buried leach pad liners. Photo 8 shows the location of a hand excavated test pit to collect a sample of the existing PVC geomembrane liner for testing. Photo 9 shows an existing liner test sample removed from the leach pad surface. Photo 10 shows the cut area where a test sample had been removed and the existing liner surface had been cleaned and prepared for seaming. Photo 11 shows the cut area repaired and seamed with new PVC liner to continue leaching operations. Photo 12 shows a typical PVC liner installation in the foreground for expansion of an existing heap leach operation in the background. The liner is covered with drain fill material prior to ore lift placement.

Sample Selection

In late March 1994 the existing leach pad liners were excavated and sampled for “finger print” index testing of the PVC liner sheets. The buried liner samples were collected at the downgrade side of each pad along 4,000 feet (1,219 meter) of ore heap fill length where the liner surface had been in contact with alkaline (high pH) operational solution flows draining through the overlying drain fill cover. The purpose of the index testing was to confirm that the existing liner systems were acceptable for continued seaming to new PVC liners and for tie-in and filling of the space between the existing high heap fills with additional ore heap material. The PVC liner sheets that had been exposed to the sunlight and climatic conditions along the perimeter berm limits were examined and observed to be more rigid compared to the buried liner materials. The exposed liner areas were planned to be removed for the new PVC pad liner installation, and therefore were not tested.

The existing PVC pad liners were sampled and tested for thickness, strength, elongation, and stress-strain properties for the evaluation of the PVC liner performance over a 5 to 9 year operational time period. A list of geomembrane liner fabricators or suppliers and the time of installation of each of the existing Pads 1 to 4 is summarized on Table 1.

TABLE 1 – LINER TEST SAMPLE HISTORY

MANUFACTURER FABRICATOR INSTALLER	PAD NUMBER	CELL NUMBER	LINER TYPE	DATE INSTALLED	DATE SAMPLED
Environmental Liners	1	1	40 MIL PVC	NOVEMBER 1985	MARCH 1994
Environmental Liners	2	5	40 MIL PVC	NOVEMBER 1985	MARCH 1994
PALCO Linings	3	6	40 MIL PVC	MAY 1986	MARCH 1994
Watersaver Company	4	15	40 MIL PVC	DECEMBER 1989	MARCH 1994

Index Testing

Index testing was by a certified liner testing laboratory on each liner sample according to the National Sanitation Foundation (NSF, 1993) specification NSF-54 standard. A list of the specified minimum values for each fabricator/installer is presented in Table 2. . The test results also are compared to the PVC Geomembrane Institute (PGI) specification (PGI 1197) for the material properties and seaming requirements of PVC geomembranes that became effective in January 1997 and thus the minimum PGI 1197 values are also included in Table 2.

TABLE 2 - SPECIFIED MINIMUM VALUES FOR INSTALLATION

MANUFACTURER FABRICATOR INSTALLER	THICKNESS (mils) ASTM D-1593	TEAR RESISTANCE (lbs) ASTM D-1004	TENSILE STRENGTH AT BREAK (lbs/inch) ASTM D-882	ELONGATION AT BREAK (%) ASTM D-882	MODULUS OF ELASTICITY (psi) ASTM D-882
		MD or TD	MD or TD	MD or TD	MD or TD
Environmental Liners	38	10	92	350	900
PALCO Linings	38	10	92	300	900
Watersaver Company	38	12	92	400	1000
PGI 1197	38	10.5	97	400	N/A

Liner Test Results

The test results show that the existing PVC liners have maintained their integrity beneath the 120 foot high ore heap leach pile and the liner material properties remain within allowable specification standards. The elongation at break in the tested liners has decreased with time, possibly due to temperature changes experienced along the toe of the heap fills under shallow ore cover as well as some plasticizer loss with time. Although the percent elongation in the existing PVC liners had decreased with time, it remained more than an order of magnitude greater in value compared to HDPE liners. The testing verified that the existing buried PVC liner system could be seamed to new PVC liner materials and remained in good condition 5 to 9 years after original installation for continued ore heap leaching operations in 1995 and 1996. Test results on representative samples of the existing buried PVC liners are summarized in Table 3.

TABLE 3 – TEST RESULTS ON BURIED PVC LINER

SAMPLE LOCATION AND NUMBER	THICKNESS (mils) ASTM D-1593	TEAR RESISTANCE (lbs) ASTM D-1004		TENSILE STRENGTH AT BREAK (lbs/inch) ASTM D-882		ELONGATION AT BREAK (%) ASTM D-882		MODULUS OF ELASTICITY (%) ASTM D-882	
		MD	TD	MD	TD	MD	TD	MD	TD
PAD 1-1	37	18	15	106	95	279	305	2300	2100
PAD 2-5	37	18	16	103	95	278	366	2135	1740
PAD 3-6	39	15	14	115	108	392	394	1890	1830
PAD 4-15	38	14	12	107	96	392	394	1865	1640
PGI 1197	38	10.5	10.5	97	97	400	400	N/A	N/A

NOTES:
1. MD INDICATES MACHINE DIRECTION
2. TD INDICATES TRANSVERSE DIRECTION
3. TEST VALUES ARE AVERAGE OF 5 TEST STRIPS PER SAMPLE PVC SHEET

CONCLUSIONS

Flexible PVC geomembranes have significantly higher interface shear strength compared to the more rigid smooth HDPE geomembranes. This conclusion is based on construction observations of liner installation, drain cover fill placement, and high ore lift placement operations on leach pad liner systems. These construction observations were verified with large scale liner field test studies, laboratory testing under controlled test conditions, and recent shear strength data comparing PVC and HDPE geomembrane interface strengths (Stark and Richardson 2000). Buried PVC geomembrane index properties remained relatively unchanged for liners under ore heap leach pads for over nine years even in a harsh climate and chemical environment. These construction observations of geomembrane liner performance were verified with large-scale liner field test studies and laboratory testing under controlled test conditions.

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