Condition assessment of a 30-year old pond liner

Robert B Wallace
AECOM, USA

Justin Woolston
LOM Engineering, Australia

Peter DiDonna
Worsley Alumina, Australia

Ian D. Peggs
I-Corp International, USA

ABSTRACT: An acid containment pond, constructed in 1987 with an HDPE geomembrane liner is at the end of its functional life. A condition survey conducted in 2016 identified a very large number of damaged and deteriorated locations. Prior to exhuming the geomembrane preparatory to replacement, a program of sampling and laboratory testing was conducted to quantitatively assess the liner condition. The test results were assessed with regard to their serving as an indicator of the deterioration, and by extension, the remaining functional life. The determination of index and ageing-related

Keywords: geomembrane, longevity, exposure, condition survey

1 INTRODUCTION

Preparatory to the development of the design and construction of some pond improvements and replacement of the geomembrane liner for the SEP2A pond at the Worsley Plant site near Collie, WA, Australia, LOM Engineering undertook a sampling and testing program to evaluate the condition of the 30-year old geomembrane installed in 1987. This Technical Memorandum presents the findings and conclusions from the program, completed in July 2017.

1.1 *Background*

Solar Evaporation Pond 2A (SEP2A) was constructed at the Worsley site in 1987. The containment system was composed of a 1.5mm thick high density polyethylene (HDPE) geomembrane, installed by Geomembrane Installations PTY Ltd.

As part of the Bayer process for alumina production and for power generation, both sulphuric and hydrochloric acid are used in the process. At Worsley, the annual volume of waste acid generated is approximately 1070 tonnes H_2SO_4 and 85 tonnes HCl, which is then pumped to the solar evaporation ponds (SEPs) for containment. The ponds are lined with a geomembrane to avoid acid leaking into the surrounding environment.

This paper addresses the condition of the HDPE geomembrane installed to contain the waste acid materials, with a pH of between 0.7 and 1.2. Data exist for the fluctuation of pH levels contained in the pond over 30 years of exposure. As a component of facility upgrades, the liner has been scheduled for replacement with a new liner. In 2016, with the pond near capacity, the acid was neutralised with process water (pH 12), then drained back to the Refinery Catchment Lake, to supplement the cooling water volume.

Pond SEP2A is shown on Figure 1.

The notable features of the SEP2A HDPE-lined pond are as follows:

Storage capacity: 0.88 GL

Dimensions: 350m x 200m x 14m deep

Internal batter slope: 1V:2.5H.

Due to the Mediterranean climate of the south west of Western Australia, there is a net evaporative loss, with the result that the acid storage pond filled slowly over the last 30 years. Since 2000, there has been a significant reduction in the average annual rainfall at the Refinery, falling from 1350mm at inception, to 870mm.

Figure 1. Pond SEP2A

2 2016 CONDITION SURVEY

In 2016, a walkover inspection of the liner was undertaken, which identified 1078 defects in the upper 10m of the batter slope; the lower 2m and floor area still being submerged. Of these defects, 246 were holes that had penetrated the liner and allowing leakage with a further 524 defects identified that would require repairing, including dents scratches and partial cuts. There were 308 locations where the welds were considered poor or suspicious and, in most cases, these were extrusion welds. Some of these welds were readily pulled apart by pulling the extrusion bead by hand.

There were also major tears including a 15m seam split and locally, the liner had not extended sufficiently into the anchor trench to secure the panel.

At mid-height on the eastern batter slope, hydraulically upgradient of the groundwater flow direction, slumping as a result of shallow slope failure beneath the liner had occurred, with the liner bridging the slip scarp, in tension.

3 2017 SAMPLING AND TESTING PROGRAM

3.1 *Sampling program*

Samples were collected from contact points of the liner, ranging from locations that have never contacted the acid (always above the wetted surface), but exposed to ultraviolet (UV) radiation; locations that were virtually continuously submerged in the acid, and virtually no UV exposure; and locations along the spectrum between these limits.

Samples were collected from the sideslopes of the pond, on the south, east, and north sides. In each case, samples were collected as follows:

- *Anchor trench* – representing geomembrane that has been protected from the elements since it was installed. These samples will not have been exposed to ultraviolet (UV) radiation or mechanical damage from equipment, animals, man, or other causes. Unfortunately, the logistics of site activities prevented sampling of the anchor trench location on the east and north sides.
- *Top of slope* – representing geomembrane that has been exposed to UV throughout the year, but has not been exposed to the pond's contents.

- *Mid-slope* – representing geomembrane that has been exposed to UV when the pond is empty, but has been exposed to the pond's contents for at least some of the pond's life.
- *Bottom of slope* - representing geomembrane that has been exposed to some UV when the pond is empty, but has been exposed to the pond's contents for most of the pond's life.

This distribution of sample locations allows us to consider the range of exposure conditions over the life of the geomembrane, currently, 30 years. This range extends from complete non-exposure, as exemplified by the liner buried in the anchor trench, to an area with near-continuous exposure to the elements due to its location above the typical high liquid level. Two intermediate conditions are included within the sample range.

Figure 1 also shows the locations of the sampling lines in SEP2A (dated photo - pond is currently near empty). Although difficult to make the distinction from the test data, it should be noted that in the southern hemisphere, the exposure of the liner on the south (north-facing) slope will be more pronounced than on the other sides. This is discussed further in the evaluation of the test results.

The sample size collected for laboratory testing was initially about 1.5m square. Each sample was subdivided into several smaller samples to facilitate shipping to the laboratories. Unfortunately, the reduced sample size (into multiple sample coupons, or individual pieces) was too small to complete some of the testing. As a result, it was necessary to collect additional samples for the Multi-axial tests.

3.2 *Testing program*

A menu of laboratory tests was performed on the samples, to evaluate index and mechanical properties of the materials, as well as testing associated with long term ageing and durability.

3.2.1 *Index and mechanical properties*

Index and mechanical properties are those which are utilized principally as a measure of manufacturing quality control. They are not used for design. However, in this case, they are used to quantitatively evaluate the condition of the geomembrane after the 30 years since it was installed. Table 1 presents the results of the Index and Mechanical properties testing.

The results shown have been consolidated. The results are the average values obtained. Outliers that tend to skew these average values are discussed below.

Table 1. Index and mechanical properties.

Test	ASTM	Spec. Value	Units	Anchor Trench	Top of Slope	Mid-slope	Bottom of Slope
Thickness	D5199	1.5	mm	1.63	1.62	1.59	1.58
Density	D1505	0.94	g/cm^3	0.949	0.953	0.953	0.952
Carbon Content	D1603	2 - 3	%	2.38	2.50	2.68	3.03
Carbon Dispersion	D5596	1 or 2	Category	1	1	1	1
Melt Flow Index	D1238	0.16-0.29	g/10 min	0.19	0.15	0.17	0.13
Yield Strength	D638	22	N/mm	32	34	32	34
Yield Elongation	D638	12	%	18	16	16	16
Break Strength	D638	16	N/mm	37	34	36	37
Break Elongation	D638	100	%	603	478	585	552
Puncture Resistance	D4833	400	N	141	485	307	386
Tear Resistance	D1004	87	N	54	186	119	152

It should be noted that the applicable material Specification that applied to the supply and installation of the geomembrane in 1987 is not known. "Typical" specifications are shown on the tables herein, which reflect current specifications for geomembranes.

3.2.2 *Ageing and durability properties*

Ageing and durability properties include those tests that address residual strength and resistance to ultraviolet radiation (UV) and endurance of the geomembrane. These properties make it possible to quantitatively evaluate the condition of the geomembrane after the 30 years since it was installed, and estimate the remaining functional life of the material.

Table 2 presents the results from ageing and durability properties. Average values are shown.

Table 2. Ageing and durability properties.

Test	ASTM	Spec. Value	Units	Anchor Trench	Top of Slope	Mid-slope	Bottom of Slope
NCTL @ 200 hours	D5397	>200	hours	>200	122.2	142.0	152.7
Standard OIT	D3895	>100	minutes	27.0	14.1	24.0	36.2
High Pressure OIT	D5885	>400	minutes	317	126	162	209
Multi-axial tensile	D5617	None	kPa	---	16,525	15,308	16,080
Multi-axial elongation	D5617	20 - 30	%	---	13.3	12.8	14.9

4 DISCUSSION OF TEST RESULTS

4.1 *General*

The discussion presented herein relates solely to the observation and test results conducted for this program. Hence, the observations developed in the condition survey previously conducted by others (WML Consultants, 2016) are supplementary to this quantitative presentation. The previous survey developed observations with regard to liner damage by conducting a comprehensive walk-over of the liner and concluded that the liner was at the end of its useful life. We do not draw any other conclusions from that work. They visually noted hundreds of locations where damage or deterioration of the geomembrane was evident; however no photographic documentation was provided.

The test results presented herein do allow us to draw conclusions on the condition of the geomembrane. The following sections document the results and provide discussion and conclusions based on those results.

4.2 *Representative trends*

As previously noted, the distribution of the samples collected was developed in order to allow us to observe the liner conditions under different exposure conditions. These ranged from zero exposure (anchor trench samples); to continuous exposure (top-of-slope samples); and in between (non-continuously exposed samples and occasionally-exposed samples). In truth, the anchor trench locations and bottom-of-slope locations were very similar, representing areas that generally had the least lifetime exposure. The mid-slope samples reflect an intermediate degree of exposure.

Consistent with this assumption, it is noted that in general, the “best” results were obtained from the anchor trench samples, and the bottom-of-slope samples. The “worst” results are shown from the top-of-slope samples, followed by the mid-slope samples. With specific examples, this is presented in the following sections.

4.3 *Index and mechanical properties*

As noted above, the relative exposure of the samples over the lifetime of the geomembrane range from zero in the anchor trench; to slight, at the bottom of the slope, where near-continuous liquid cover was present; to the mid-slope, where exposure ranges from zero (below the water level) to full (during low water operations); to continuous, at the top of the slope, above the water line for all, or almost all of the operating life.

There are, however, few distinguishing indications from the sample locations with regard to these index properties. It is noteworthy that for the properties of puncture resistance and tear resistance, there are two “groupings” of test results: results considerably lower than the specification, and results much higher than the specification. In the absence of the precise specification for this material, and particularly the actual conformance results for the material, it is difficult to make a judgement on the significance of this. We do know that manufacturing quality control in that era was not anywhere near as precise or reliable as geomembranes manufactured today so, for now, we accept those values as representative. This is substantiated in part with the test results for thickness, which range from 1.44mm to 1.75mm for nominal 1.5mm thick material. We would not see this spread on new material today. It is possible that there has been some swelling of the material in response to contact with the very low pH acids stored in the pond, but there is insufficient information to properly decipher this cause and effect of such exposure.

Nevertheless, at face value, many of the index properties do not reflect deterioration over time in the test results. The tensile strength numbers are generally good compared to the specification.

The only real conclusion that we draw from this is that these parameters are subject mostly to the variation in manufacturing quality control. These tests are not specifically indicative of the current condition of the liner. The deterioration over time is best exemplified by the testing of what we call Ageing and Durability properties.

4.4 *Ageing and durability properties*

Ageing and durability properties include those tests that address residual strength and endurance of the geomembrane. These properties make it possible to quantitatively evaluate the condition of the geomembrane after the 30 years since it was installed. The ageing and durability properties considered include those shown in this category in Section 3.2 of this report.

As noted above, the relative exposure of the samples over the lifetime of the geomembrane range from zero in the anchor trench; to slight, at the bottom of the slope, where near-continuous liquid cover was present; to the mid-slope, where exposure ranges from zero (below the water level) to full (during low water operations); to continuous, at the top of the slope, above the water line for all, or almost all of the operating life. Ageing, represented by a deterioration of these properties, would thereby be expected to range from maximum to minimum at the Top of slope, Mid-slope, Bottom of slope, and Anchor trench.

One of the principal drivers of geomembrane deterioration over time is oxidation, which is principally fed by high temperature and UV exposure over its life. Oxidation is therefore linked specifically to the exposure factor of the geomembrane, and is why those areas of the installed geomembrane that are specifically sheltered have the lowest deterioration (such as in the anchor trench). Stabilizers that are added to the polymer as the geomembrane is manufactured reduce the oxidation reaction, but these stabilizers are consumed over time. However, the materials that the geomembrane is exposed to (in this case, very low pH acids) also contribute to depletion of the stabilizers, and often are a predominant cause even more so than ambient factors.

The OIT test is a measure of the remaining protection, with the conclusion drawn being more qualitative than quantitative. It should be noted, however, that geomembranes manufactured today are provided with much improved stabilizers, extending oxidation times from geomembranes manufactured at the time of this installation.

This is evidenced in the ageing-related test results:

- NCTL – essentially no stress crack ageing in the anchor trench, with reduced values progressively from the Bottom, Mid, and Top locations, based on the average values shown in Table 4. However, notably, the individual values as shown in Table 1, are inconsistent, with all test results on the East side passing the 200 hour limit. On the North side, the lowest value was tested at the bottom of the slope. An anchor trench sample was only collected on the South side.
- Standard OIT – these test results complied with the expected high to low progression as stated above;
- High Pressure OIT – not all samples were tested by this method, but the tests that were performed followed the expected high to low progression as stated above; and
- Multi-axial tensile – the test results from this testing do not show a particular pattern, although the elongation at failure was much lower than the original material.

Of particular note, however, is the significant deterioration of the NCTL stress crack and Standard OIT test results as compared to the new material. In general, in the stress crack testing, the geomembrane has deteriorated between 25% and 40% in the areas exposed to UV to varying degrees. Yet, the unexposed sample from the anchor trench did not reflect any change in the new-condition results. The Standard OIT testing indicated a decrease in antioxidant levels between 64% and 86%. Somewhat unexpectedly, the anchor trench sample also showed a large decrease, at 73%. The High Pressure OIT tests gave similar indications to those of the NCTL tests, with the anchor trench sample reflecting a 20% decrease, and with the variously exposed samples indicating a decrease ranging from 52% to 68%.

These three tests are most indicative of deterioration over time of the geomembrane. It is not realistic to define a remaining life factor based on these tests, but it is reasonable to conclude that the results showing more than a 50% decrease reflect that the geomembrane is nearing the end of its practical life, and based on individual results, arguably, has arrived at that point.

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Similarly, the High Pressure OIT testing shows significant deterioration, and with the highest to lowest values following the expected (Anchor trench – bottom – mid – top) trend. Again, overall, the losses are significant.

4.5 *Consideration of welds*

It is not clear what processes were used to weld the geomembrane when it was installed. Observations made at the time of the condition assessment in 2016, by others, indicated that although the principal means of welding was fusion welding with a double-track apparatus, there were extensive areas in which extrusion welds prevail. This was also noted during the present program. In the 1980's, it was still common for all production welding of geomembranes to be conducted using extrusion apparatus; however fusion welding was becoming favored as a methodology as productivity (m/minute) was much higher and, arguably, fusion welding resulted in a better connection. Today, production welding is universally conducted by fusion welders. Extrusion welders are only employed for repairs, penetrations, connections to other structures, and difficult access locations. At the time of this construction, both methods were still employed, but typically, if fusion welding apparatus were available, they would likely have been used for the entire installation.

Consequently, it may well be that what we are seeing of these welds, is that fusion welding was employed for production welds, and extrusion welding for repairs. This is disturbing, because there is a high proportion of extrusion welds, implying that weld quality during installation was not good.

In the report on liner condition, the liner inspection identified 308 locations where poor welds were noted that should probably be repaired – and most of those were extrusion welds. It is not out of line to assume that these deficient welds were repairs.

No testing of welds was conducted in this program, principally because the ageing of the geomembrane itself was being evaluated and the condition of the welds, although critical to performance, was not necessarily time-related. Those deficient welds have likely been deficient since installed. As noted, it appears that the extrusion welds are predominantly repairs; however, it is not known whether these were repairs conducted at the end of installation, prompted by failing weld integrity tests, or if they were performed after some period of operation, during which poor weld condition was noted and repaired.

In any case, the weld condition serves to exacerbate the overall condition of the liner, even though not directly related to ageing. No testing is recommended for weld samples.

5 CONCLUSIONS

The condition of the SEP2A pond geomembrane reflects its 30-year age. This liner has severely depleted antioxidant content, lowered stress crack resistance, and poor strength and mechanical-resistance properties, notably tear resistance and puncture resistance. The liner will continue to deteriorate as long as it remains in place and exposed to the elements.

A reasonable distribution of liner sampling and testing has provided consistent test results that are indicative of a geomembrane at, or at least rapidly approaching the end of its practical life. Continued operation, even with repairs, will tend to result in ongoing problems related to leaking and structural failure of the liner. We recommend that the geomembrane be removed and replaced by a new 1.5mm thick HDPE geomembrane. There have been many improvements to the formulation and manufacture of geomembranes subsequent to the geomembrane in place here. A new geomembrane, properly installed with high quality Construction Quality Assurance (CQA), can reasonably be expected to last 40 to 50 years under the same conditions.

It should be noted that although not specifically addressed herein, the condition survey noted over 1,000 locations in the liner that required repair if there was to be any consideration of continued operation. Some of this damage appears to reflect damage that has been progressively caused by elements of operations, although this is simply an extension of the concern for the material itself. Most of these locations could be repaired; however, this is impractical, and in light of the tested and observed condition of the liner, especially related to ageing and durability, removal and replacement is the only realistic conclusion.

It is therefore concluded that the liner has effectively reached the end of its practical life, and should be replaced.

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