High Performance Geomembranes in Aggressive Mining Applications

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ABSTRACT

Operating conditions associated with mining activities can generally be classified as aggressive environments. Liquor retention ponds, evaporation ponds and tailings dams are some of the mining applications which require geosynthetic liners with specific mechanical and chemical compatibility properties, which are usually the focus of owners and designers when assessing suitable geomembrane materials. Previous project specifications have often been adopted without consideration of the lessons learnt in previous long term mining applications. Additionally, the impact of environmental ambient conditions can be overlooked or given second order priority during the assessment process. This paper discusses the approach taken by an Australian project team to select a suitable geomembrane material for use in a critical evaporation pond application containing a very acidic liquor with very high UV exposure combined with very high maximum ambient temperatures exceeding 40 deg C. The project team underwent an extensive testing protocol to better determine how a combination of factors influenced the material assessment process and final material selection.

BACKGROUND

To support ongoing mining operations, a significant mining company in Australia required additional evaporation pond capacity. Located in a region of Australia subject to very high solar irradiance, regularly exceeding 28MJ/m^2 per day, and subsequently very high UV exposure and very high maximum ambient temperatures in excess of 40 deg C not commonly experienced at other mining locations globally (refer Appendix A, Table 4. Average Climate Statistics for the Site). The mine facility, which has been operational for over 30 years, uses evaporation ponds to manage acidic liquor decanted from the tailing's retention and storage facility. The liquor has an average pH of 0.79 and, as can be anticipated in such an application, is high in metallic oxides and chlorides.

The existing tailings and evaporation ponds were lined with GRI GM13 compliant high density polyethylene geomembranes; however, the mining client had experienced some variability in the performance of HDPE geomembranes in the same applications at this particular site. Despite advances in polyolefin additive packages over previous decades, the client had witnessed unexpected material degradation with HDPE liners in more recent evaporation ponds. The evidence from site was supported by numerous studies on the degradation of polyolefin materials when exposed to higher temperature operating conditions (Bhartu 2015). When other mine sites with similar operations were referenced, it was realized these reference sites in North and South America did not experience the same level of solar exposure (refer Figure 1.) (Solargis, 2022).

As part of their internal assessment process, the client instigated an assessment of the performance of the geomembrane materials installed in the existing evaporation ponds. Samples were exhumed from various positions in the existing evaporation pond to analyze the effect of the liquor and environmental conditions. The results would be used to determine the testing and selection criteria of the geomembrane for the new facility, and ultimately, the material type.

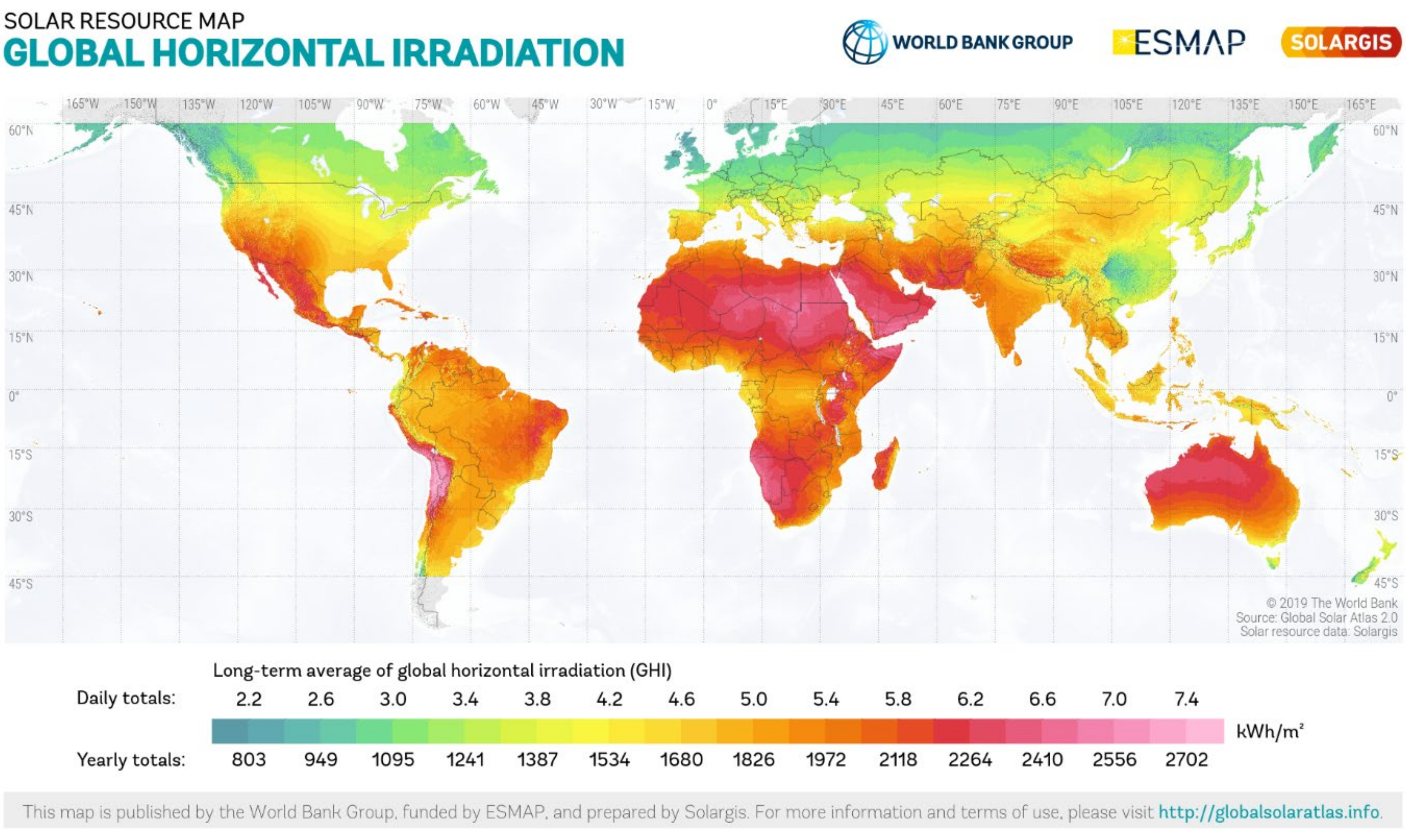

Figure 1. Solar Exposure & Australia's higher exposure than North & South America

METHODOLOGY

Geomembrane samples were taken from various locations in the existing evaporation pond to analyze the effect of the acidic liquor and environmental conditions. Samples were taken from the floor area which was continuously exposed to acidic liquor and sediment containing high concentrations of metallic oxides and chlorides, from the sloped batter walls in the intermediate wet/dry zone, and from the anchor trench where the liner was not exposed to liquor or ambient environmental conditions.

The exhumed geomembrane samples were then tested by an independent laboratory experienced in geomembrane testing, to determine the remaining ultra-violet (UV) stabilizers and antioxidant (AO) package. Results were then analyzed using Arrhenius mathematical modelling to estimating remaining life expectancy based on depletion rates of the AO and UV stabilization packages. The testing revealed the acidic liquor was not the primary source of degradation and provided some level of protection from climate related degradation processes, whereas areas above the liquid line exhibited significant reductions in AO and UV stabilization packages (refer Table 1.). The estimated service life of the geomembrane on the batter slopes exposed to the “splash zone” was less than half that of that predicted for the geomembrane section on the floor that was continuously exposed only to the acidic liquor. A significant reduction in the antioxidant package was also observed in the HDPE geomembrane material exhumed from the anchor trench that had not been exposed to either the acidic liquor or UV. This finding was completely unexpected. It was theorized this could be due to the heat soak of the earthen embankment during summer months, potentially reaching temperatures of 35 deg C.

	a) Floor Sample	b) Wall Sample	c) Anchor Trench
Exposure	Continuously exposed to acidic liquor.	Fully exposed at the intermediate wet/dry zone.	No exposure to liquor or environmental conditions.
Remaining AO package.	63%	13%	50%
Remaining UV stabilizers	75%	32%	67%
Estimated residual life remaining.	12 years	2 years	6 years
Total estimated service life	22 years	9 years	16 years

Table 2. Existing geomembrane remaining AO/UV stabilizers and estimated life expectancy

As a result, the client initiated a comprehensive material selection process to evaluate potential materials during the design phase of the new evaporation pond, commencing with an expression of interest for supply of suitable materials. The evaluation included high performance and regular high density (HDPE) and medium density (MDPE) polyethylene's, polyvinyl chlorides (PVC), ethylene interpolymer alloys (EIA) , bituminous (BGM) and geosynthetic clay (GCL) liner materials. After receiving submissions from manufacturers and suppliers, a desktop review was undertaken by the client subsequently reducing the number of potential materials from eight to four.

SELECTION CRITERIA

When the expression of interest was requested, Layfield (the Manufacturer) conducted a formal review of the Client's test results, the application, the location and associated environmental factors of the existing HDPE liner material. The main degradation mechanisms in the application were identified as UV exposure, high geomembrane surface temperatures and chemical exposure to very acidic liquid with the splash zone of the liner being exposed to all three degradation mechanisms.

An analysis matrix was subsequently completed by the Manufacturer to determine the most appropriate material. HeatGard, a raised temperature HDPE (PE-RT) geomembrane produced from a bi-modal polyethylene resin having the highest ranking. This PE-RT resin is a proprietary formulation polymerized using a dual gas phase reactor to produce a HDPE resin with unique properties. During development of the geomembrane, the resin Manufacturer and the geomembrane Manufacturer worked together closely to produce a formulation incorporating a significant antioxidant and UV stabilization package, specifically suitable for exposed applications in aggressive environments.

UV Resistance:

UV Resistance is achieved in the geomembrane with a substantial UV stabilization package developed specifically for exposed geomembrane applications. In addition, the carbon black loading of 2-3% provides an impenetrable surface to UV light eliminating concurrent sub-surface degradation of the material. The Manufacturer's UV testing of 1600hrs in accordance with ASTM D7238 has shown an exceptionally high 99% retention of high-pressure oxidation induction time (HP-OIT) results to ASTM D5885.

Geomembrane Surface Temperatures:

It is well known that surface temperatures of exposed black geomembranes significantly exceed ambient temperatures when exposed to solar radiation. The mine site is known to receive extremely high solar radiation levels, averaging in excess of 28MJ/m^2/day in summer months. Temperatures on black geomembranes in similar regions in Australia have been recorded at:

Shaded conditions (Ambient): 50 deg C.
Exposed to direct solar radiation: 80 deg C.
Exposed to direct & reflected solar radiation: 123 deg C.

In this application it was assumed that the liner would not be exposed to any reflected incidence and therefore maximum temperatures were expected to reach 80 deg C. At this temperature, the antioxidant package in standard grade HDPE geomembranes would deplete rapidly (Abdelaal and Rowe, 2014) and as experienced by the client in existing storages on site. Oven aging testing and Arrhenius modelling undertaken by the Manufacturer was able to predict anti-oxidant depletion rates at the temperatures expected to be experienced by the geomembrane liner at the mine site, as shown in Figure 2. (Mills and Beaumier, 2017).

Chemical Resistance – Acid:

The geomembrane proposed by the Manufacturer has very high resistance up to 30% sulfuric acid at 60 deg C, – well above the expected liquor temperature and maximum recorded 5% sulfuric acid present in the existing storage. There was further evidence from the existing storages that polyethylene has the necessary chemical resistance to the contained liquid.

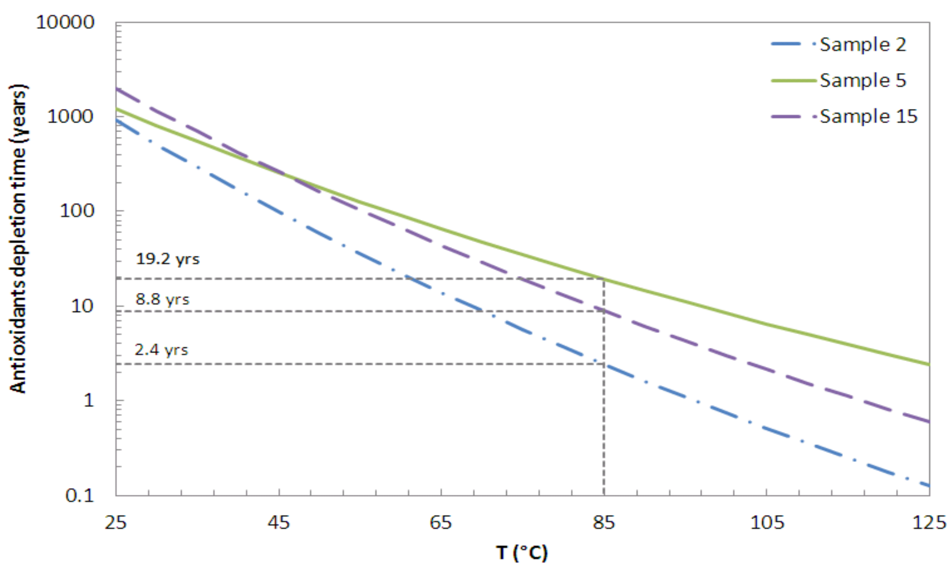

Figure 2. Arrhenius modelling of antioxidant depletion rates at elevated temperatures.

The antioxidant package used in the geomembrane has significant resistance to hydrolysis. Many of the antioxidant packages used in standard geomembrane resins contain a phenolic antioxidant with an ester, which suffers attack by acidic liquids. The antioxidant package used in the selected geomembrane contains a dendrimeric structure that does not suffer from hydrolysis.

MATERIAL TESTING

The client engaged a specialist engineering consulting company to evaluate the suggest geomembrane materials and determine a suitable testing regime to evaluate the short listed materials, and once a material was selected, to provide manufacturing quality assurance. After an initial desktop review, four candidate geomembranes were shortlisted. A specialist polymer testing laboratory was engaged to undertake a significant testing regime. In addition to the standard test criteria set out in GRI GM13 additional testing was used to simulate accelerated in-service conditions (Folwell, Gassner, and Phillips, 2021). This testing focused on the primary degradation mechanisms of chemical attack from the acidic liquor, and UV exposure with high temperatures.

The client provided sufficient liquor solution to the test laboratory to undertake 90 day immersion testing in accordance with ASTM D5322 and ASTM D5747 to replicate the expected chemical exposure. Samples of virgin geomembrane, fusion welded geomembrane and extrusion welded geomembrane were all immersion tested at 55 deg C, 70 deg C and 85 deg C and material performance was evaluated using Arrhenius modelling of OIT depletion rates to estimate the service life of the geomembrane.

Reduction in tensile results can potentially give an early indication of any performance issues with the geomembrane's chemical resistance properties after immersion testing. Tensile tests were undertaken on virgin samples to create a base line and after immersion for 30, 60 and 90 days in accordance with ASTM D6693.

Stress crack resistance of HDPE geomembranes is also critical in the long-term performance of the material. Notched Constant Tensile Load (NTCL) SCR testing was undertaken in accordance with ASTM 5397 on virgin geomembrane samples prior to immersion and after immersion for 30, 60 and 90 days at 55 deg C.

90 day Oven Aging in accordance with ASTM D5721 and UV exposure for 1600 hours in accordance with ASTM D7238 was also undertaken to assess the geomembrane performance with respect to degradation above the waterline on the exposed slopes of the storage.

Oven aged samples were subjected to both standard and high-pressure oxidative induction time testing in accordance with ASTM D3895 and ASTM D5885. Virgin samples were initially tested to determine a baseline performance and samples removed at 30, 60 and 90 days to assess the degradation rate of the oxidation induction time.

At the conclusion of the testing the high performance PE-RT geomembrane was selected as the most suitable material due to it's very low reduction in OIT and HP-OIT performance after immersion testing, oven aging and UV exposure and due to it's very high NTCL stress crack resistance.

MANUFACTURING REQUIREMENTS

In addition to standard, in-house quality assurance testing and monitoring in accordance with GRI GM13, the client required specific material performance properties to be tested with a higher frequency, and for testing to be duplicated at an independent test laboratory to corroborate the in-house test results (refer Table 2. & 3.). As some of these tests are of significant duration, index type test results were signed off to allow the geomembrane material to be shipped while the endurance properties were still undergoing testing. The material was then signed off and accepted for installation after the endurance testing was completed for each batch. Completing the shipping and endurance testing concurrently truncated the material supply lead times significantly.

Property	Test Method	Manufacturers Laboratory	Independent Laboratory
Thickness	ASTM D5199	Per Roll	Per Roll
Tensile Properties Strength at break Elongation at break Strength at Yield Elongation at yield	ASTM D6693	Per 5 Rolls	Per 5 Rolls
Tear Resistance	ASTM D1004		
Puncture Resistance	ASTM D5397		
Carbon Black Content	ASTM D1603		
Carbon Black Dispersion	ASTM D5596		
Density	ASTM D1505		
MFI	ASTM D1238		

Table 2. Index properties tested by manufacture and independent test laboratory.

Property	Test Method		Manufacturers Laboratory	Independent Laboratory
Oxidative Induction Time Standard OIT **AND** High Pressure OIT	ASTM D3895 ASTM D5885		Per resin batch or per 60 rolls	Per resin batch or per 60 rolls
NCTL Stress Crack Resistance	ASTM D5397	1000 hrs		
UV Resistance High Pressure OIT retained	ASTM D7238 ASTM D5885	1600 hrs		
Oven Aging at 85 deg C Standard OIT	ASTM D5721 ASTM D3895	90 days		
Oven Aging at 85 deg C High Pressure OIT	ASTM D5721 ASTM D5885	90 days		

Table 3. Endurance properties tested by manufacture and independent test laboratory.

For additional quality assurance, the client required the geomembrane manufacturing process to be witnessed by an independent quality audit team. This was facilitated by the manufacturer in close collaboration with the client, engineering consultant and auditing company.

CONCLUSIONS

Many mining sites are located in aggressive environments and the affect on geomembrane materials is exacerbated by mineral extraction processes often producing liquors with extremely low acidity or very high alkalinity. When specifying materials, Engineers need to consider the significant influence of environmental factors as well as consider the chemical compatibility of the

Figure 3. The completed storage facility in operation.

proposed materials. Samples taken from an existing geomembrane lined storage on site clearly demonstrated the impact of environmental factors exceeded the impact of exposure to very acidic liquor.

Undertaking a thorough materials evaluation process prior to materials specification has clearly identified the benefits of using a high-performance PE-RT geomembrane in this application. With this knowledge the client could proceed with construction with a high level of confidence that the material performance would exceed the expected life of the storage. It also demonstrated the benefit of open collaboration between the client, engineering consultant and geomembrane manufacturer during the evaluation and manufacturing phases, leading to the successful completion of the project (refer Figure 3.).

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APPENDIX A – AVERAGE SITE CLIMATE STATISTICS

Statistic Element	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
Mean maximum temperature (Degrees C)	37	35.6	32.2	27.3	22.3	18.5	18.7	20.8	25.3	28.6	32.1	34.7	27.8
Highest temperature (Degrees C)	48.5	46.8	43.2	40	33	27	29	34.6	39	42	47.4	47.4	48.5
Lowest maximum temperature (Degrees C)	17.5	18.9	18.5	17.3	13	12	11	9.8	16	14.9	17.9	22	9.8
Decile 1 maximum temperature (Degrees C)	30	28.6	25.5	22	18.1	15.6	15.2	17	19.4	22	25.3	28	
Decile 9 maximum temperature (Degrees C)	43.5	42	38.8	33	27	21.8	23	25.5	32	36.6	39	41.8	
Mean number of days >= 30 Degrees C	27.6	23.7	21.3	8.5	0.8	0	0	0.5	6.2	12.3	19.2	24.8	144.9
Mean number of days >= 35 Degrees C	20.3	16	9.7	1.3	0	0	0	0	1.1	4.7	9.4	15	77.5
Mean number of days >= 40 Degrees C	10.1	6.1	1.4	0	0	0	0	0	0	0.3	2.4	5.5	25.8
Mean minimum temperature (Degrees C)	21.2	20.1	17.2	12.8	8.2	5.1	4.3	5.6	9.3	12.8	16.4	19	12.7
Lowest temperature (Degrees C)	11.5	11	5	1	-3	-6	-5	-4	-1.1	2.2	6	8	-6
Highest minimum temperature (Degrees C)	33	33.7	28.5	24	19	15.5	14.8	18.5	25	26.2	30	32.8	33.7
Decile 1 minimum temperature (Degrees C)	16	15	12	7.2	3	-0.4	-0.8	0.2	4	7	11.2	14	
Decile 9 minimum temperature (Degrees C)	27	26	22.7	18.6	14	11	9	11.1	15.1	19.1	22.9	25	
Decile 1 monthly rainfall (mm)	0.3	0	0	0.2	0.4	0.8	0.4	0	0	0	0.1	1.1	52.3
Decile 5 (median) monthly rainfall (mm)	4.1	6.6	2.5	4.2	9.3	4.9	2	4.9	5	5.5	10	10.2	132.6
Decile 9 monthly rainfall (mm)	43.8	44.8	23.2	37	18.2	45	17.7	25	28.2	32	35.2	35.8	230.6
Highest daily rainfall (mm) for years	52	61.6	36.2	86	17	45	13	17.4	24.6	41	40	48.8	86
Mean number of days of rain for years	3.2	2.8	2.6	3.3	3.3	4.2	3.3	3.8	4	3.8	4	4.2	42.5
Mean daily wind run (km)	424	396	353	296	276	264	289	325	379	396	405	415	352
Maximum wind gust speed (km/h)	94	76	94	70	81	74	70	74	93	91	109	93	109
Mean daily solar exposure (MJ/(m*m))	28.6	26	22.2	17.1	13.1	11.2	12.2	15.4	19.8	23.9	26.7	28.4	20.4