

What is UV Radiation Exposure and Heat doing to your Liner?

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ABSTRACT

Research has shown that prolonged exposure to ultraviolet (UV) and elevated temperature can accelerate the process of oxidation which in turn can reduce the strength of geosynthetic materials. In South Africa the temperature in most regions can reach the upper 30's which may result in the temperature on exposed, black geomembranes to be in excess of 60°C. In August 2013, the South African Regulator, the Department of Water Affairs, released new Norms & Standards for the design of waste disposal facilities. In the license review process to obtain design approval of waste management facilities, the service life, related to aging of geosynthetics, must be found to be sufficient compared to the 'polluting life' of the materials being contained by the barrier system. In this paper the effects of UV and heat exposure on geomembranes using four case studies of geomembranes installed at sites in three different provinces, will be presented by comparing any available baseline properties of the liner to the properties after a period of exposure.

1. INTRODUCTION

The degradation of geomembranes due to temperature and ultraviolet (UV) exposure has been and is currently the topic of research by many worldwide researchers. Simply stating that an HDPE will last a long time is no longer acceptable both to many waste management facility owners as well as regulators. Designers are required to show that the geomembrane (as well as other components of the barrier system) will outlast the contaminating lifespan of the waste deposited in the lined facility. The contaminating lifespan has been described by Rowe (2010) as the time during which a landfill will produce contaminants at levels that could have unacceptable impact if they were discharged into the surrounding environment. Landfill monitoring has shown that liner system temperatures of 30-40°C can be expected (Jafari et al. 2014) while even temperatures as high as 60°C (Rowe 2005) have been recorded where there was a high leachate mound above the liner. The effect of these high temperatures, when sustained, can have detrimental effects on the liner system; specifically geomembranes are discussed in this paper.

The recently promulgated South African Norms and Standards by the Department of Water Affairs (2013) require that the design engineer takes the service life of the HDPE geomembrane in consideration in the design however the service life required in years is not stated as has been seen in some regulations like Ontario (Canada) Regulations (Jafari et al. 2014). In the South African climate ambient temperatures may reach and exceed the upper 30's which alone, apart from any reactions with of the waste contained, can elevate the temperature of exposed liner to above 60°C due to the carbon black mechanism of converting UV radiation to infra-red radiation (heat).

The information contained in the study is from a database that the designers are creating and continuously updating for research purposes in order to better understand the actual aging of geomembranes at different sites. This actual data will assist in the reviewing of theoretical lifetime prediction models.

2. TEMPERATURE EFFECTS ON LINER

Hsuan et al. (1995) state sunlight, heat and radiation as the three types of energy which should be considered in the oxidation behavior of a geomembrane with sunlight highlighted as a major concern on exposed geomembrane due to photodegradation. Heat on the other hand can be due to direct sunlight as well as generated by the waste being stored. A geomembrane will degrade faster at a higher temperature. Covering of a geomembrane can prevent sunlight (UV) exposure and also reduce the direct heat from the sunlight.

A liner can be described as failed when the leakage rate exceeds acceptable or initially determined action leakage rates or when visible stress cracking can be seen in areas of exposed materials. Koerner et al. (2012) use the half life as an indication of degradation. This is when there's a 50% change in the strength or elongation of the material. The aging process of HDPE geomembranes occurs due to both physical and chemical aging which happen at the same time. Hsuan et al. (1995) describe the physical aging process as a slow one and the chemical aging as the more important degradation mechanism that leads to a reduction in engineering properties. The chemical aging process occurs in three stages of depletion time of antioxidants, induction time to the onset of polymer degradation and lastly the degradation of the polymer to decrease some property to an arbitrary level such as its half-life. The chemical aging process is shown in Figure 1 below.

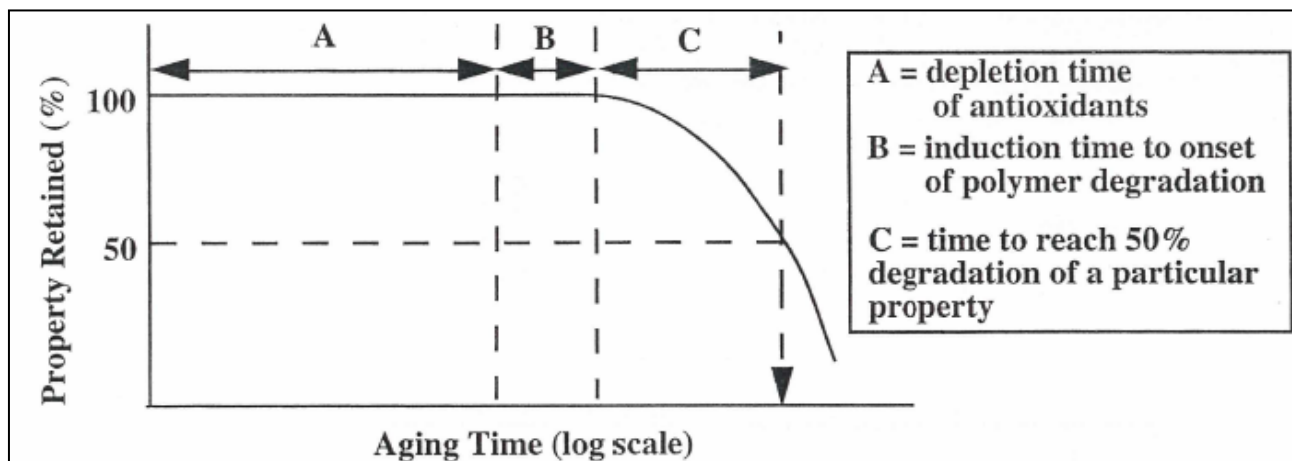


Figure 1: The stages in chemical aging of HDPE geomembranes

Antioxidants are added in a HDPE geomembrane formulation to prevent the degradation during processing, installation and to prevent oxidation reactions taking place during the first stage of service life (Hsuan et al. 1995). The depletion time of antioxidants will vary between different manufactures depending on the antioxidant package used in the formulation. In the induction period the oxidation reaction starts occurring before measurable degradation can be seen. This period is longer in stabilized polymers as the antioxidants create an additional depletion time. In the final stage the oxidation happens rapidly resulting in changes to the installation physical and mechanical properties of the material. The material becomes brittle, loses its tensile and yield strength and fails. Based on the stages discussed above the specification of OIT compliant material cannot be over-emphasised but there are two school of thoughts with regards to whether either the standard or high pressure oxidative induction time (OIT) should be specified as per GRI-GM 13 or both should be required. Manufactures are able to produce material that meets both requirements when requested to.

Once the material has degraded it can be seen on the surface of the material by the resultant stress cracks. At this stage it is already too late to implement any preventative measures. Accelerated UV Radiation Tests such as those done in a QUV apparatus in accordance with the ASTM standard D7238 can be performed to determine when the reduction in a critical parameter will result in a failure of the material. This value can then be compared to polluting lifespan and a decision on an appropriate cover or protective layer can be made to be implemented during the initial construction.

A sampling and testing regime is proposed by Peggs (2008) where a baseline is established for each installation and changes from that are monitored periodically for timely repairs or replacements where possible. These may be cases like stormwater or leachate storage facilities which could be emptied for access to the liner. For landfill cells it may prove almost impossible or unreasonably costly to remove waste that has been landfilled over many years for repairs and other means of preventing the contaminants from polluting the environment, such as groundwater cut-off systems, may be employed. Since only one opportunity exists at these facilities to install the liner, it is very important that the design takes into account the required lifetime.

3. CASE STUDIES

The three sites from which case studies are taken are situated in three, inland provinces of South Africa namely Gauteng, Limpopo and Mpumalanga. All three can be defined as hot climates as the daily temperature during the summer season have been recorded as high of 45°C.

3.1 CASE STUDY 1: RELINING OF A LEACHATE STORAGE FACILITY FOR CONVERSION INTO A LANDFILLING CELL

The cell was constructed in 1998 and was approved for temporary storage of leachate. The primary composite of the lining system consisted of a 2mm thick, smooth HDPE geomembrane in contact with 4x150mm thick compacted clay liners. After almost 11 years of operating as a dam the cell could be emptied and equipped with a leachate collection system for the purpose of landfilling in 2009. This was seen as an opportune time to conduct tests on the geomembrane to assess whether it had degraded and if it needed to be replaced as there had been much technological development in the use of geosynthetics since the date of construction. As no baseline or reference parameters of the geomembrane at the time of installation was available, samples were taken from the anchor trench to represent the unexposed condition. Samples were taken on the exposed section of liner that was above the water level and as well as below the water level. The results are compared in Table 1.

Table 1: Results of testing

Properties		GRI-GM13	Test done on samples from:			
			Anchor trench	Top exposed	Middle slope (in leachate)	Base of Cell (in leachate)
1	Thickness (mm)	nom. (-5%) = 1.9	1.96	2.06	2.02	2.02
		lowest = -15% (1.7mm)	1.83	1.98	1.98	1.98
2	Density (g/cm3)	0.94	0.947	0.946	0.95	0.95
3	Carbon Black %	2-3%	2.51	2.44	2.51	2.87
4	Yield Strength MD (kN/m)	29	39.7	36.6	38.8	39
5	Yield Strength TD (kN/m)		41.8	37.6	39.8	40
6	Break Strength MD (kN/m)	21	36.5	33	39.3	39
7	Break Strength TD (kN/m)		36.7	31.1	31.6	34
8	Yield Elongation MD (%)	12	19	22	20	19
9	Yield Elongation TD (%)		19	22	19	18
10	Break Elongation MD (%)	100	414	458	491	485
11	Break Elongation TD (%)		420	364	276	399
12	HPOIT	400	293	250	343	388
13	Stress resistance Crack	300	245	358	308	416

The material was found to have properties that met the GRI-GM 13 specification except for the HPOIT values. The exposed sample was found to have the lowest HPOIT value while, strangely the samples below the water level were found to have higher HPOIT values than the buried anchor trench sample. The higher stress crack resistance value was also unexpected. The material strength properties decreased when exposed except for the yield elongation in the transverse direction that increased.

At the facility the specification for current cells was that the material be both Standard OIT and HPOIT compliant and it was clear that the in situ material was failing this criteria. There were also difficulties on site to remove sludge over the geomembrane without damaging it. The decision was then taken to replace the geomembrane with a GRI-GM13 compliant material meeting both the STD and HP OIT times. The testing done was not comprehensive to explicitly conclude that the degradation of the material was solely due to temperature and UV effects. Attack from the leachate stored was another possible mechanism of degradation. The swelling (increase in thickness) and increase in density of the aged material are likely due to leachate absorption.

3.2 CASE STUDY 2: USE OF GEOMEMBRANE STOCKPILED ON SITE UNPROTECTED FOR TWO YEARS

A cell was designed to be constructed in consecutive stages each immediately following the completion of the previous. Liner material (1.5mm thick double textured GRI GM 13 compliant material) was however sourced for the entire area. During construction of the first cell it became evident that the next cell would only be required at a much later stage and hence the construction of the next cells was postponed. Two years later another area in the same facility required lining and the material on site as per initial conformance test results was found to be suitable for the specification – GRI-GM 13. As part of the construction quality assurance program samples were taken for conformance testing and to act as a baseline for the new area that the material was to be used at. The geomembrane had been stockpiled on site without any cover in a region with an average ambient temperature of 32°C in the summer months. The results showed that the material was failing either the standard OIT specification or the break at elongation specification; the two most commonly used parameters to test degradation. A more intensive testing regime was undertaken in order to make a decision on the use of the materials. Ten samples were taken at the edges of the rolls in question as well as some mid-sheet representing the unexposed condition. A roll was also randomly selected in the middle of the stockpile as this would have been protected by the surrounding rolls. The initial results have shown that only material on the outside of the stockpile and specifically the exposed edges of the rolls were affected. An instruction was immediately given that all liner be covered to prevent exposure as the material was still to be stockpiled for a further period before being installed. At the same time, QUV testing was performed on one of the samples that had failed to meet the specification for a better understanding of the degradation mechanism. The sample was exposed to 1600 hours of UV exposure composed of 80 cycles of UA at 75 C for 20 hours followed by condensation at 60 C for 4 hours. The HPOIT was evaluated before and after the exposure and results show a retention of 66% of the baseline HPOIT. This supports the instruction to cover the material and slow down the rate of degradation. The material is also to be quickly covered after it has been installed.

3.3 CASE STUDY 3: INVESTIGATION TO MOTIVATE INCLUSION OF A BALLAST LAYER FOR FUTURE EXTENSIONS OF DISPOSAL FACILITIES AT A SITE

When an overflow between two phases was required at the site an opportunity arose to sample liner that was installed 6 years ago in order to assess the degradation it had experienced from being exposed for the period. The primary geomembrane installed was 2mm thick HDPE and GRI-GM13 compliant; in fact it greatly exceeded the project specification (by at least 16% in terms of the break elongation and 467% in terms of HPOIT). Liner was sampled at the free board level (exposed) as well as middle and bottom levels where it had been covered with waste. Baseline data was available as conformance testing was conducted during the construction in 2008.

The HPOIT result of the top geomembrane indicates that only 6% of the original anti-oxidant package remains within the geomembrane. Although the current HPOIT value has significantly decreased, it provides 29% of the HPOIT specification requirement. The HPOIT results of the Middle and Bottom geomembranes are still relatively high compared to the specification. However, both of these have dropped to 60% of the original HPOIT value. This indicates that depletion of the anti-oxidants may be due to high temperatures as these two geomembranes were not exposed to UV light but were located below the Top geomembrane. However, the rate of deterioration due to raised temperature is slower than due to the combination of UV rays and high temperature experienced by the Top geomembrane. In terms of tensile properties, the break strength and elongation in the machine direction have reduced to approximately 80% of their original values. These values are still however marginally above the material specification.

From the results it could be seen that where the material was covered by waste it had degraded at a lesser rate and still met the specification. From this it could be concluded that an engineered soil layer could be used to limit or slow down the rate of antioxidant depletion. The decision was taken to design a suitable ballast layer that could be placed with minimum risk to puncture the geomembrane in the next phase.

3.4 CASE STUDY 4: INVESTIGATION TO MOTIVATE EXTENSION OF A LEACHATE COLLECTION LAYER UP THE SIDESLOPES OF A LANDFILL EARLIER THAN REQUIRED

A landfill extension was constructed and completed in 2013 for extension of landfill operations at a disposal site. The cell will however only be required at a later stage due to a decrease in the airspace consumption rate and availability of airspace in other existing cells. The primary liner consists of a 2mm mono-textured HDPE geomembrane that has been covered at the base with a sand protection layer as well as the leachate collection layer. The protective and collection layers would be incrementally extended up the slope as landfilling progressed. This would avoid the veneer stability failure of the thin layer of material up the entire sideslopes without support. If the full installation is to be done immediately, a geogrid would need to be installed that would support the weight of the collection layer without inducing tensile stains on the geomembrane; a function for which it has not been designed for.

During construction, conformance testing was conducted and the geomembrane was found to have very high values of HPOIT, in the region of 4000 minutes; that is ten times higher than the specified value. A sample of the material was taken and sent for further testing. It was exposed to 1600 hours of UV exposure composed of 80 cycles of UA at 75 C for 20 hours followed by condensation at 60 C for 4 hours. The HPOIT was evaluated before and after the exposure and found to retain 96% of its HPOIT value. The results, as well as the lifetime prediction calculations will guide the decision on how long the sideslopes can remain exposed.

4. DISCUSSION

The geomembranes used in the four case studies discussed above were all from different manufactures, of different thicknesses and installed by different contractors. The only similarities are the hot climates in all three regions and the designs were conducted by the same consultants. All four case studies have shown degradation of exposed geomembranes with time. Although the degradation cannot be exclusively accredited to temperature and UV exposure effects; the further QUV testing conducted strongly supports UV exposure as a significant cause.

Recently some geomembrane manufactures have started producing high temperature geomembranes that they report can withstand temperatures as high as 100°C while providing the required environmental protection. Such geomembranes may have a place in the industry as temperatures this high have been recorded and reported in some landfills as well as heap leach pads. Jafari et al. (2014) present a case history where high temperatures were recorded due to the exothermic aluminium reactions that occurred in the waste body generating considerable heat. Given the relatively short history of high temperature geomembranes in landfill applications their effectiveness cannot be assessed in this paper. Currently the cost of such materials may be prohibitive at some large sites that protective, insulating covers on geomembrane may render a cheaper alternative.

The following conclusions can be made from the current database:

- Temperature and sunlight exposure is an issue of major concern that should be considered in the design of lined facilities.
- Exposed geomembrane solutions, like dams, should be reassessed.
- It is important to record the baseline parameters of an installed geomembrane and store an archive sample that may be used later for comparison purposes.
- Liners stored in stockpiles should be covered with suitable UV resistant materials to prevent degradation due to sunlight exposure even before the material is installed.
- High temperature geomembranes have a place in the industry although not much case histories are available on these materials as they haven't been widely used.

Further research continues in this subject as the consultants gather more data from different sites to compare against available baseline data.

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