Designing geomembrane capping layer for long term performance: A case study of closure of tailings storage facility in BHPBilliton Worsley Alumina

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ABSTRACT: An HDPE geomembrane cap was selected for the closure of a 50 Ha Tailings storage facility in Western Australia. A 1000 year design life for the geomembrane was targeted to meet the stringent environmental and longevity requirement of the project. To maximize the resistance to surface oxidation and the initiation of stress cracking, the material was specified with significantly higher stress cracking resistance, oxidative induction times, oven (thermal) aging resistance, and UV resistance, than the GRI.GM13 standard specification. A comprehensive Manufacturing Quality Assurance (MQA) program of plant audits, material sampling, and laboratory testing was implemented. Stress cracking and oven aging results required some special consideration. A careful investigation, detailed analyses and implementation of stringent MQA program resulted in a material that met the requirements of all parties to the project prior to shipping from North America to Australia.

1 BACKGROUND

Closure and rehabilitation of Tailings Storage Facilities (TSFs) are important parts of all mining and mineral processing operations. BHPBilliton Worsley Alumina Pty Ltd (BWAPL) operates five TSFs termed Bauxite Residue Disposal Areas (BRDAs) in a refinery in Western Australia. The first of these, commenced in 1984, reached the ultimate stage for closure and rehabilitation in 2000 (Figure 1).

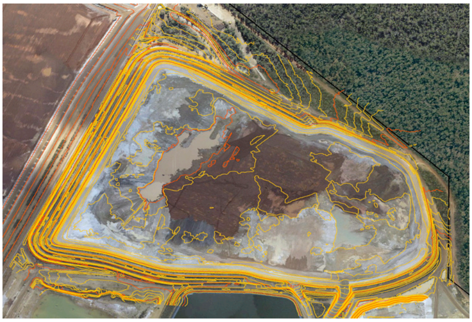

Figure 1. Bauxite residue disposal Area 1. Surface prior to closure works

The stringent closure requirements to ensure long term environmental protection required a robust capping system. Since 2000, BWAPL has commissioned several researches into long term and sustainable closure methodology which has resulted in selection of the ‘Store and Release System’ (SRS). The components of the SRS design include:

(i) A composite barrier layer consisting of compacted clay liner (CCL) overlain by a High Density Polyethylene (HDPE) geomembrane that will completely isolate the residue from the environment and also limit infiltration of surface water;

(ii) A sand drainage layer above the geomembrane that acts to release excess water; and

(iii) A soil vegetation layer to support and sustain plant growth.

This paper presents engineering investigations into the selection and design of the HDPE barrier layer to ensure performance in excess of 400 year lifetime and preferably up to 1000 years. While current technology does not guarantee that any covered liner installation will have a 1000 yr service life it was incumbent upon the project Superintendent and design consultants to use/specify an HDPE with maximum durability, since not all HDPE geomembranes have the same durability.

Clearly, with the present level of HDPE geomembrane technology, manufacturers and design engineers do not guarantee that the material will last for a thousand years. However, it is possible to define and investigate the significant durability parameters and to specify them at the highest practical level.

However, this must be done in a combination that would not preclude material from being made to meet these specifications. The tale is often told of the geomembrane designer who specified the highest property values of different geomembrane materials to derive the “super geomembrane” that could not, of course, be manufactured.

2 HDPE GEOMEMBRANE SELECTION

While there are many manufacturers of HDPE geomembranes, most of the products have essentially identical physical and mechanical properties; density, tensile strength/elongation, tear strength, puncture resistance, thermal expansion coefficient, thermal conductivity, etc. Where they do differ, and differ significantly, is in their stress cracking resistances (SCR) and in their resistance to thermal and photo-oxidation.

There are many HDPE resins that are used to make geomembranes, and the different HDPE resins are reacted with different co-monomers to counter HDPE’s susceptibility to stress cracking (SC). Stress cracking is a quasi-brittle cracking that occurs under a constant stress lower than the yield or break stress of the material. It is one of the fundamental characteristic of HDPE which, if not carefully considered, can lead to poor performance in service. Many natural gas distribution pipe failures in the late 1970s (American Gas Association) and many geomembrane failures in the 1980s (Peggs India) have been attributed to stress cracking. It appears not to be a significant performance problem these days as resins have been improved, although we only have about 30 years experience with HDPE geomembranes. However, it is one of those parameters that should be maximized to obtain optimum service lifetimes, particularly since long term stresses cannot be avoided on capping systems such as adopted in this project.

The literature is full of laboratory research into lifetime predictions of HDPE liners under different service conditions, but there is little practical experience because HDPE geomembranes have only been used for 30 or 35 years. End of lifetime (EOL) in all HDPEs will occur by oxidation and stress cracking, starting on the surface and working inwards. Theoretical lifetimes of properly specified, properly installed and tested buried HDPE geomembranes have been projected at several hundred years (Koerner 1998, Müller, 2007). However, two known exposed HDPE geomembranes have reached EOL after only 12 and 15 years (Peggs, 2009), although many others have been in service for more than the last 30 years. With such a range in performance, the selection of the appropriate geomembrane to meet longevity requirements of the BRDA projects was critical.

HDPE geomembranes are protected against thermal oxidation and photo-oxidation (UV) by the addition of stabilizers, and also against UV by the addition of carbon black which gives HDPE its black color. Raw HDPE resin is white. The resin manufacturer typically compounds stabilizers in with the resin, but the geomembrane manufacturer may add more. Alternatively, the geomembrane manufacturer may add all of the stabilizers. These formulations are generally highly proprietary, for they affect the rate at which the geomembrane can be manufactured, its cost, and its performance. Rarely are these stabilizers customized to suit specific environments. Thus, a geomembrane that will have a long exposed lifetime in the Arctic will have a much shorter lifetime in the Sahara desert. And, clearly, the actual time to EOL will be a synergistic function of the HDPE resin (stress cracking resistance), the formulation of the stabilizer additive package (oxidation resistance), the quality of welding (surface notches and added oxidation), the quality of installation (notches and residual stresses), the ambient service temperature range (oxidation and contraction stresses), and exposure to UV radiation (photo-oxidation). Clearly each installation is unique. Hence the need to practically maximize a combination of the significant durability properties to achieve the longest possible performance.

With respect to the requirements of the capping design for this project, the properties affecting the durability parameters are primarily stress cracking resistance (ASTM D5397) and thermal oxidation resistance (standard oxidative induction time, S-OIT, ASTM D3895 and high pressure oxidative induction time, HP-OIT, D5885). Both evaluate the amount of stabilizers in the material and thus the amount of available protection; S-OIT at 200°C and HP-OIT at 150°C. HP-OIT is more meaningful since 150°C is closer to the service temperature.

3 INVESTIGATING PRACTICAL LIMITS OF HDPE DURABILITY PARAMETERS

Since the most critical requirement was longevity, specific emphasis was placed on achieving the highest yet practical stress cracking resistance (SCR), oxidative induction times (OIT), and oven aging (thermal) resistance. UV resistance was not of the highest significance since the geomembrane would be covered. However, a good UV resistance would support optimum thermal resistance.

At present most HDPE geomembranes are manufactured to meet the specifications of the Geosynthetic Research Institute GRI.GM13 standard. When first introduced in 1997 the specified stress cracking resistance was >200 hr. In 2004 the SCR was increased to >300 hr and several manufacturers are now using >400 hr. Standard oxidative induction time (S-OIT) was first used to assess the level of antioxidants in the material, but this has been supplanted by high pressure OIT (HP-OIT) since the mid 2000s . To determine the maximum practically achievable specifications several independent geosynthetics testing laboratories and resin manufacturers were consulted. While SCR of the better resins was exceeding 20,000 hr it was recognized that this would not be achieved on the geomembrane itself. The specifications selected, compared to the GRI.GM13 standard are shown in Table 1.

Table 1. Material durability specifications

Parameter	ASTM Test	GRI.GM13	Project Specification
SCR	D5397	>300 hr	>1500 hr
S-OIT	D3895	>100 min	>150 min
HP-OIT	D5885	>400 min	>525 min
Oven aging S-OIT	D5721/ D3895	>55% retained	>75% retained
Oven aging HP-OIT	D5721/D5885	>80% retained	>85% retained
UV resistance HP-OIT	D4355/D5885	>50% retained	>80% retained

From Table 1 above, it is clear that specifications for this project were more stringent than the internationally recognized GRI.GM13 specification for "an HDPE geomembrane" in all cases. For example project specified SCR >1500 hr against GRI requirements of SCR>300 hr. GM13 requires S-OIT and HP-OIT to be 100 min and 400 min respectively, but the project specified >150 min and >525 min respectively. GM13 requires retained thermal resistance S-OIT and HP-OIT values to be >55% and >80% respectively, while the project requirements were >75% and >85% respectively. Project requirements for UV resistance was >80%, against GM13 requirement of retained HP-OIT to be >50%.

These specifications were presented to selected HDPE geomembrane manufacturers in Europe, North America, and S. E. Asia for the supply of material. All but two declined the request for proposal, being concerned that such parameters, particularly the SCR of >1500 hr, could not be met. Visits were made to the manufacturing facilities and quality control laboratories of the two responding manufacturers to audit the complete manufacturing and quality processes and records, from incoming resin to outward shipping in containers. There was still some resistance to the SCR specification but the project team was confident that a geomembrane SCR of >1500 hr could be achieved with at least one of the resins offered. After several discussions between the key stakeholders involving the need to balance quality requirements and project economic factors without unduly compromising cap longevity, a suitable manufacturer was selected. The selected manufacturer also proposed adding a little more stabilizer to ensure that the increased OIT values would be met. The manufacturer's written guaranteed specifications are shown in Table 2.

Table 2. Project and Manufacturers specifications

Parameter	ASTM Test	GRI.GM13	Project Spec.	Manuf. Spec.
SCR	D5397	>300 hr	>1500 hr	>400 hr
S-OIT	D3895	>100 min	>150 min	>150 min
HP-OIT	D5885	>400 min	>525 min	>525 min
Oven aging S-OIT	D5721/ D3895	>55% retained	>75% retained	Not to be used
Oven aging HP-OIT	D5721/ D5885	>80% retained	>85% retained	>80% retained
UV resistance HP-OIT	D4355/ D5885	>50% retained	>80% retained	>50% retained

4 MANUFACTURING QUALITY ASSURANCE (MQA)

The MQA engineer made another visit to the plant at the start of the three stage production run to confirm the records that would be required and to familiarize the MQA monitor with procedures and records. Full time MQA was not performed, but the monitor made 3 random visits to the plant during each of the three manufacturing periods to remove 3 samples of material each time for conformance testing. Records were checked to ensure that the same resin was used throughout the manufacturing period and that the additional stabilizer had been consistently added. In addition to performing their own in-house MQC testing, the manufacturer sent part of our samples to another independent testing laboratory.

5 OBSERVATIONS DURING MQA TESTING

All conventional index properties were easily met. Stress cracking resistance tests were stopped a little after 1500 hr and all but one sample met this specification. This one sample (five test specimens) had one specimen at 1297 hr and four specimens that broke after 689, 678, 709, and 668 hr. An unusual double crack growth pattern was evident on the fracture face of the 1297 hr specimen (Figure 2) which has only been seen once before (Peggs, 2008). The cause is not known. After much consideration this sample was accepted on the basis that all specimens in other samples taken from the same resin batch met specifications and the specimens well-exceeded the highest industry specification of 400 hr. In retrospect there were also some concerns about the quality of the notching procedures at the CQA lab during that period. However, a more significant concern occurred in the measurement of HP-OIT which the manufacturer thought would relatively easily be met.

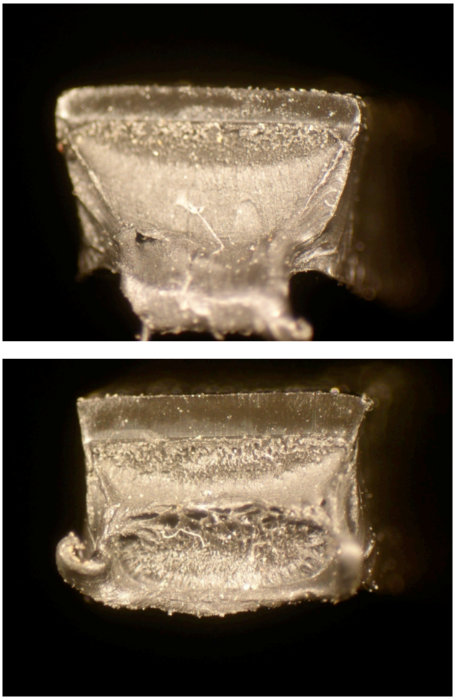

Figure 2. Stress cracking fracture faces with dual cracks below. Notch at top.

Although the HDPE for this project would be buried during its service life, both thermal oxidation (oven aging) and UV resistance tests were performed as required by GRI.GM13. These are 1600 hr and 90 day/hr tests respectively. Before production of actual project material started, the manufacturer agreed to start these two tests on similar material, and to measure HP-OIT after 15, 30, and 60 days, such that when production did start the tests would be completed, hopefully successfully. This was to ensure that by the time the first lot of production material was sampled and tested, its 15,30,and 60, day exposure results could be compared with the reference data to see if trends were acceptable or not. Unfortunately, the manufacturers' tests were only started a couple of weeks before the production conformance tests. Shortly into the tests it became apparent, as shown in Table 3, that the material might fail these tests.

Table 3. OIT test results and extrapolations to end of oven aging test.

Laboratory	Baseline (min)	60 day (min)	% retain	90 days extrapolated (min)	% retain extrapolated
HP-OIT					
QA Lab	791	655	83	580	73
QC Lab	752	495	66	360	47
Resin Manuf.	683	524	77	450	66
Geomembrane Manuf.	752	564	75	470	63
S-OIT					
QA Lab	165	68	42	25	19
QC Lab	157	59	38	25	19

After 60 days of thermal exposure extrapolation of conformance test results indicated that HP-OIT retained at the conclusion of the test would be about 68% rather than the manufacturer guaranteed 80%. The manufacturer's data were also indicating the same. Similarly, tests performed by the resin manufacture also indicated a possible failure. However, it was also clear that there was some variation between the single specimen test results from the three different laboratories. At the same time similar different test results were being obtained on another manufacturer's HDPE geomembrane samples being tested at the same two independent laboratories.

An analysis of specimen preparation and testing procedures at the two well-respected GAI.LAP (Geosynthetic Accreditation Institute – Laboratory Accreditation Program) accredited laboratories revealed some differences in procedures resulting from each laboratory's perceived "improvements" to the basic ASTM D5885 procedure. For instance, the ASTM D5885 standard requires that small discs be stamped from the geomembrane, melted into a plaque and a disc specimen stamped from that to be diced into pieces for testing. One lab prepared the specimen directly from the disc cut out of the geomembrane. They also tested baseline and exposed specimens in the two-place specimen holder of the equipment, but cross-talk between the two positions was ultimately found. The other laboratory stamped discs from the geomembrane sample, melted the discs and rolled a plaque from which three specimens were cut. These were tested individually.

Ultimately it was decided that both labs would stamp discs out of the geomembrane, make a standard ASTM D4703 plaque, and stamp three discs from that. DSC tests would be performed on single specimens after a very careful cleaning of the specimen holder and chamber. The results were more consistent and showed the retained HP-OIT to just meet the manufacturer's specification of >80% - 80.3% for MQA testing and 83.1% for MQC testing. . Subsequently, steps were taken to modify the ASTM standard to accommodate the necessary changes to the procedures.

Conversely the UV resistance testing returned a retained HP-OIT of 89.2% compared to the project specified 80% and the manufacturer's guaranteed 50%.

The material was delivered to site and installed by an experienced installer to a comprehensive CQA plan with full time on-site CQA. One of the features of the CQA Plan was for seam specimens to meet shear elongation and peel separation requirements of 200% and 0% respectively. All five shear and all five peel specimens of each sample were to meet these specifications. It was also required that all grinding marks made in preparation for extrusion welding be covered by the weld bead and that at no location should there be any more than two weld beads in order to minimize local oxidation. The smooth clay surface on which the geomembrane was placed is shown in Figure 4. The sand layer being placed on the geomembrane is in Figure 5, and Figure 6 shows the overall finished cap.

Figure 4. Clay surface prior to laying of HDPE

Figure 5. Sand being placed on HDPE cap

Figure 6. Capped BRDA-1

6 CONCLUSIONS

Given the fact that an HDPE geomembrane would be used to cap the BRDA for a target 1000 year lifetime the material specifications were prepared to obtain the maximum practical durability parameters to maximize the time to both critical surface oxidation and the initiation of stress cracking These parameters were SCR, S-OIT, HP-OIT, oven aging, and UV resistance. Values significantly higher than those in GRI.GM13 were selected.

Comprehensive in-plant MQA auditing and MQC and MQA testing programs were performed.

All material delivered to the site was acceptable to all parties before shipping.

Comprehensive CQA and CQA programs were followed during geomembrane cap installation and when it was covered by soil to ensure life-shortening features were not introduced.

ACKNOWLEDGEMENT

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