Development of a New Higher Performance Bi-Modal HDPE Geomembrane

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Abstract. This paper presents the development of a next-generation high-performance HDPE geomembrane designed to meet increasing demands for chemical resistance and elevated temperature performance. Driven by the need to contain more aggressive liquids under harsher environmental conditions, the innovation process spanned six years and included extensive production trials, laboratory testing, and field validation. Key evaluations included tensile strength at elevated temperatures, chemical immersion tests with brine, chlorine, and leachates, and environmental stress crack resistance comparisons between standard unimodal HDPE and a new bi-modal HDPE. The bi-modal resin offers enhanced molecular weight distribution, resulting in superior chemical resistance, strength at elevated temperatures, antioxidant retention, and improved stress crack resistance. Following successful commercialization, the geomembrane was selected for a major mining project in Australia to contain highly acidic mine liquor. Additional testing at Queen's University confirmed its effectiveness against municipal leachates and PFAS. This paper highlights the rigorous testing and innovation required to advance geomembrane technology and explores higher temperature applications in mining, waste management, oil & gas, utilities, and renewable energy particularly in response to rising global temperatures and increasingly aggressive containment needs.

1 Background

As containment specialists we have constantly been challenged to find geomembranes for new and unusual applications. The challenges usually focus on chemical compatibility, long term durability, physical properties, and/or temperature. This paper discusses some of the research done to investigate geomembranes for elevated temperatures.

Many geomembrane installers rely on their resin and sheet manufacturers to answer their application questions. As a manufacturer, fabricator, and installer, we were in the unique position of having contact with the end users and to have development resources in-house. We were also in contact with industries in challenging environments such as oil and gas, oil sands, heavy oil, mining, forestry, waste management, utilities, alternative energy and chemical manufacturing.

Some of our first high temperature challenges were to find geomembranes that could withstand high temperatures for short term containment. One of our first applications was to find a geomembrane for the secondary containment of transformer oil. In electrical substations the oil-filled transformers typically operate at temperatures near 148C (298F). We needed a geomembrane that could withstand the splash of hot oil in the event of a major spill. The solution to this challenge was to enlarge the containment area and then fill with an open granular material. The design was for the full volume of oil to only come to the top of the granular material. In the event of a large spill the granular material would absorb the heat quickly enough to protect the liner. The geomembrane selected in this case was a reinforced PVC/EVA alloy. The granular material was lightweight expanded clay aggregate (LECA) which has a very high surface area.

Our second short term high temperature application was a bottom liner for a sulphur block. Sulphur blocks are poured when the price of sulphur is low, and the client chooses to stockpile the material. Liquid molten sulphur is poured at about 125C (257F) into forms 100 mm (4 inches) thick, one lift at a time. Once each lift is cooled the forms are raised and the next lift is added. Completed sulphur blocks are typically 15 m (49 ft) high. Our challenge was to find a geomembrane that could resist the temperature until the first lift cooled. This was the first use of a geomembrane for liquid molten sulphur, so the client hired us to perform development trials. The trials were successful, and a major sulphur block facility was built. The geomembrane chosen was an unreinforced PVC alloy. This research is covered in the paper, "Geomembranes for the Containment of Sulphur; A Case History," (Mills, 1993).

The Alberta oilsands produce a thick, viscous bitumen that needs to be heated or diluted before use.

We were challenged to provide geomembranes for the short- and long-term secondary containment of heated oilsands storage tanks. There were two parts to this research, short term containment of heated petroleum liquids in the event of a spill. And the long-term resistance of the geomembrane to the temperatures under the tanks. Since the tanks are continuously heated the temperature of the geomembrane buried under the tank would reach tank temperature soon after construction. A series of geomembrane materials were identified during this testing with varying degrees of chemical and heat resistance. The results of this research are outlined in the paper, "Development of high temperature resistant geomembranes for oil sands secondary containments," (Mills, Martin, 2008).

In many regions of Australia ambient temperatures can reach 45C (113F) in the summer and geomembranes are regularly challenged by high temperatures. We were asked to investigate a particularly difficult application which was the long-term storage of brine solutions (salt water). The storage temperature of a brine pond can typically reach 60C (140F) for extended periods, and the temperature of produced water (coming up from an underground oil formation) can reach 80C (176F) or more. The results of this research confirmed that our proprietary polyolefin materials were suitable for hot brine containment. The results are outlined in the paper, "Geomembrane Resistance to Hot Brine in Produced Water and Flowback Applications," (Mills, 2015).

Temperature played a part in another Australian containment issue, the containment of potable water. Initially there were instances of lined rainwater storage tanks having problems, but then a large containment at a mining site developed unusual symptoms. Part of the problem at the mine site was that the storage temperature of the water was as high as 45C (113F). But they were also using reverse-osmosis water which led to water that was deficient in calcium. Our research showed that chlorinated, calcium-depleted water could be damaging to geomembrane materials. The results of our research are outlined in the paper, "Geomembrane Performance Testing - Impacts of a Negative Langelier Saturation Index on Geomembranes," (Fraser, Mills, 2015).

With this background we were constantly watching for materials that would fit our higher temperature geomembrane applications. We were also looking for a material that would address the difficult containment of hot, chlorinated, calcium depleted water.

2 Polyethylene for Raised Temperature (PERT)

Polyethylene has been used to make geomembranes for many years. Low density polyethylene (LDPE) was initially used for irrigation canal liners in thicknesses of 8 and 10 mil (.10 and .25mm) in the 60's and 70's. In the 80's we saw the first use of high-density polyethylene (HDPE) in geomembranes. The first high density polyethylene's were at least twice the thickness of standard 30 mil (.75 mm) geomembranes because of welding limitations. The early HDPE welders deposited a heavy bead of molten polymer in the seam, and the geomembrane had to be thick to prevent the weld bead from melting through the sheet. Although early HDPE geomembranes were 60 to 80 mil thick (1.5 to 2.0 mm) and required cumbersome welders for installation they caught on quickly due to low cost, good UV life, and excellent chemical resistance.

By the late 80's the use of HDPE geomembranes had spread widely. Wedge welders were introduced that simplified welding and new specifications were put into place that established HDPE as the liner of choice for landfills.

But the HDPE geomembranes had a problem. Polyethylene, and especially HDPE can fail through a mechanism called Environmental Stress Cracking (ESCR). If the HDPE material is subjected to stress in the presence of certain chemicals, it can crack suddenly. Factors that increase the risk of ESCR are increased density, certain types of chemicals (especially soaps and surfactants), overheating during welding, and the amount of stress.


Figure 1. Photo of stress crack

The geomembrane industry took steps to reduce the risk of ESCR in HDPE geomembranes. In the early 90's new standards were developed for HDPE that improved the additives, improved installation Quality Control, and developed a new stress crack test. They also lowered the density of the resins used from HDPE to medium density polyethylene (MDPE). The name HDPE stayed with the material even though they were now technically MDPE geomembranes.

The new MDPE geomembrane resins were taken from the plastic pipe industry. Plastic pipes are subjected to constant stress that can result in failures due to several stress cracking modes. Work done on MDPE developed for pressure pipe led to the manufacture of MDPE geomembranes with a very low ESCR risk.

MDPE geomembranes have served very well for a number of years but are occasionally challenged. The lower density has led to a lower tensile strength and a lower chemical resistance. Chemical resistance has shown to be a weakness in current state-of-the-art membranes, specifically in the presence of higher temperatures and oxidizers. A good example of this is the containment of chlorinated potable water containing commonly present water disinfectants such as chlorine gas, sodium hypochlorite/calcium hypochlorite, chlorine dioxide and chloramines. Chlorine and chlorine-based chemicals are strong oxidizers which can react with polyethylene and cause degradation. In research we have done on chlorinated water (Rangel et al 2017) we showed that MDPE geomembranes (sample 2 in the study) had a short service life.

So now we go back to pipe resins. Over the years the resin producers have been working diligently to improve the chlorine resistance of polyethylene pipe with the goal of producing a material that could be used for hot chlorinated water. This is a very difficult application as there are heat, pressure, and chlorine in combination. World-wide failures of other pipe materials such as polybutylene highlight the difficulty of containing chlorinated hot water (Zhou et al 1996).

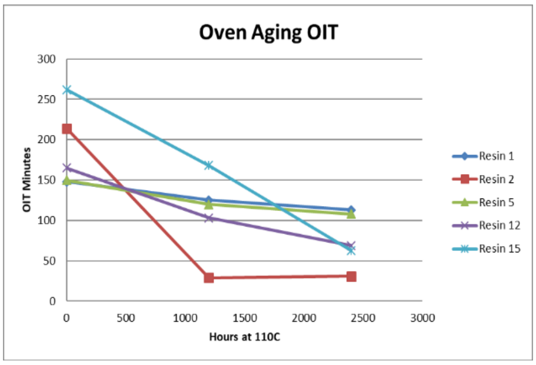

Figure 2. Oven aging results after 2400 hours

During the manufacture of polymer resins the polymer molecules form in a variety of different lengths. When you analyse the molecules formed with Gel Permeation Chromatography (GPC) you see a distribution of these chain lengths which we call molecular weight distribution. In the graph shown in Figure 3 we see a plot of the molecular weight distribution of the polymer. The bottom axis shows the molecular weight (the length of each chain). The vertical axis shows the weight fraction (how many of each chains there are). These graphs usually create a classic Bell Curve (normal distribution in statistics).

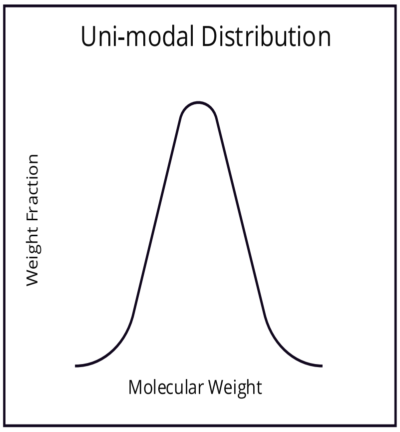

Figure 3. Uni-modal distribution

We have marked this first graph in figure 3 as a Uni-modal distribution. That means that the polymer when measured by GPC will show a single hump or bell distribution. The resin manufacturer can control the reactor conditions and change the catalysts to control the kind of polymer that is made. A very narrow distribution will be strong, stiff, and difficult to push through plastic processing equipment (all other properties being equal). A very wide distribution (graph is shorter and wider at the base) will normally be softer and more pliable, and easier to process.

When considering ESCR as a failure mechanism, in the traditional unimodal sense, the lower the density generally led to better performance (less stress cracking risk). This is a result of a higher amount of comonomer incorporation into the polymer backbone. Unfortunately, the higher the amount of comonomer, the lower the density; thus, lower chemical resistance.

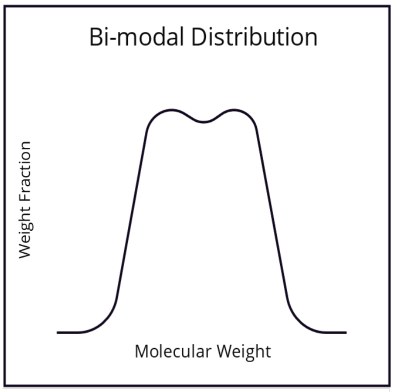

Figure 4 Bi-modal distribution

Newer resins have been using a technique that creates a Bi-modal molecular weight distribution. In the image on above, you can see a Bi-modal distribution that shows two distinct peaks on the graph. Bi-modal resins are generally made utilizing dual reactors. The first reactor has the feedstock, catalyst and comonomer injected into it where a polymer is formed with a surplus of comonomer. That material is then transferred to a second reactor operating in a comonomer-starved condition where the polymer continues to build the homopolymer backbone. The resulting resin has a very high amount of comonomer incorporated into the high molecular weight region of the GPC. This leads to a stronger crystal from both the high molecular weight portion and the lower molecular weight polyethylene. The result is a more robust product with very low risk of stress cracking.

In the pipe industry the use of bi-modal resins has resulted in new pipe materials that have been developed to contain hot chlorinated water at the highest temperature and pressure ratings. These new resins are called Polyethylene - Raised Temperature, or PERT resins. In 2013 we saw the emerging use of PERT pipe resins in Europe and thought they might have application for higher temperature geomembranes. We started by collecting 7 different pipe resins from around the world. Two of these were immediately eliminated when they would not process on our plastics extrusion equipment. That left 5 different resins to test.

While the pipe industry testing on PERT resins looked very good there was no correlation that would show how a geomembrane would work with the same resin. In 2014 we started a research project to investigate the suitability of PERT resins for geomembrane use.

3 PERT Resin Testing

Three of the initial tests on these PERT resins were: heat aging, chlorine exposure, and brine exposure. For each test we exposed the samples to three different temperatures. We evaluated them periodically for as long as two years. Overall, there were more than a thousand specimens that were prepared and tested.

3.1 Heat Aging Testing

For the heat aging test, prepared samples of geomembrane were suspended in an air circulation oven. Then at planned intervals the samples were removed and evaluated. To evaluate the geomembranes, we used a test that measures the amount of antioxidant remaining in the material. This test is called the Oxidative Induction Time (OIT) test (ASTM D3885). We compared the amount of antioxidant after exposure with the test result from the geomembrane at the beginning of the exposure. We were watching for the point where the oxidant is depleted as this is when further exposure can quickly damage the geomembrane.

Our first results came from the oven aging testing. After 2400 hours (100 days) of oven aging exposure at 110C (230F) two of the specimens showed a much more gradual decline than the other materials; Resin 1 and Resin 5. Resin 1 turned out to be unavailable commercially, so we narrowed our research to focus on Resin 5.

Because we had tested each exposure at three temperatures, we were able to develop an Arrhenius model for the performance of this new resin. An Arrhenius model lets you predict the longevity of a material at various temperatures. In Figure 5 you can see the Arrhenius model from the oven aging results. Sample 5 shows a predicted lifetime to antioxidant depletion at 85C (185F) of 19.2 years. The control specimen, sample 2, which is standard MDPE showed predicted antioxidant depletion in only 2.4 years. So, in elevated temperatures the bi-modal sample 5 dramatically outperformed the unimodal sample 2 (Mills and Beaumier 2017).

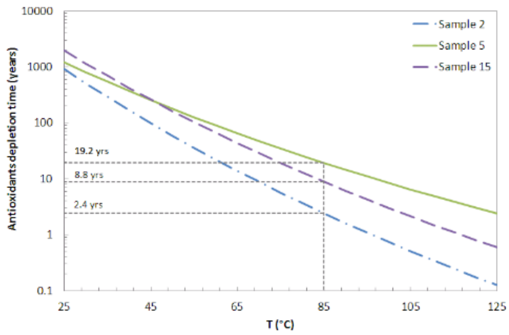

Figure 5 Arrhenius model for oven aging test

3.2 Chlorine and Brine testing

The chlorine and brine tests immersed the geomembrane samples in liquid in a test tube. To prepare the samples for this test they were moulded into a plate that was 3mm thick and then cut into bars. These bars then had a controlled slit put in them then they were bent to put stress on the bars. The bent bars were placed in a large test tube that was suspended in a hot liquid bath. This test, using the test tubes in a bath, is a standard stress cracking test (ASTM D1293). We modified this test by changing the liquid in the test tube. For the chlorine testing we used a 1% chlorine solution and for the brine we used a 30% brine solution.

In each of these testing exposures we prepared enough samples to test at three temperatures. We also prepared enough samples so that we could expose samples for as long as a year.

In this test we were also able to create an Arrhenius model for chlorine resistance. In Figure 6 we are extrapolating from higher temperatures to lower temperatures in service. In the chlorine testing the bi-modal material (sample 5) showed a predicted 56-year life before antioxidant depletion at 20C while the unimodal MDPE material (sample 2) showed a predicted life of only 3 years. This testing is written up in the paper by Rangel et al (2017).

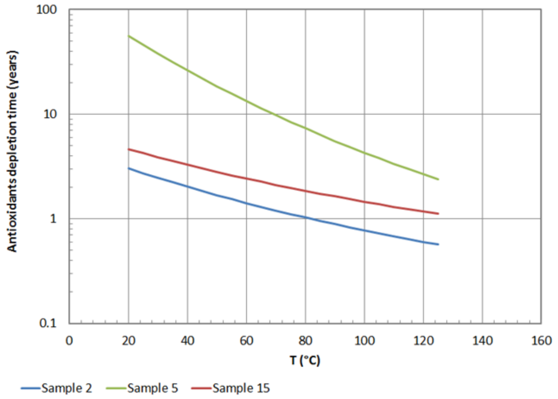

Figure 6 Arrhenius model for chlorine resistance

In the brine exposure there was a problem with one of the temperatures and an Arrhenius model could not be completed. The bi-modal resin still showed improved properties over unimodal materials. The brine testing is written up in the paper Mills et al (2019).

4 Stress-Cracking Resistance of a Bi-modal PE-RT HDPE Geomembrane

Our fifth paper written as part of the development of the bi-modal HDPE geomembrane material focused on environmental stress crack resistance (ESCR) using the Notched Constant Tensile Load Test (Sati, Beaumier 2021).

This study evaluated the stress-cracking resistance of bi-modal polyethylene raised temperature (PE-RT) HDPE, comparing it to unimodal MDPE and LLDPE geomembranes under loads ranging from 28% to 60% of yield stress. The bi-modal resin's higher tensile strength led to improved ductile failure resistance compared to standard unimodal MDPE. Notably, its failure envelope showed no clear transition from ductile to brittle behaviour, indicating a potentially longer lifespan than geomembranes made with unimodal resins.

Previous research on this material has examined tensile properties, antioxidant depletion, and resistance to brine and chlorine at elevated temperatures, consistently demonstrating enhanced durability. This SCR-focused study adds a comprehensive understanding of the key mechanisms driving the longevity of bi-modal HDPE geomembranes.

5 Project Profile

In 2019, the bi-modal PE-RT HDPE resin was commercialized as HeatGard®. The bi-modal HDPE geomembrane has been supplied into several large-scale mining and oil and gas projects. This included in 2020 when it was selected for use by BHP's for their EP6 Olympic Dam tailings pond in South Australia. This pond contained a highly acidic mining liquor in higher ambient conditions. The EP6 project included a comprehensive 12-month evaluation and testing program conducted by the owner, incorporating accelerated aging tests using aggressive tailings liquor (Folwell et al., 2021). Four different HDPE geomembrane products were assessed, with BHP ultimately selecting the bi-modal HDPE due to its superior chemical resistance, stress crack performance and thermal properties.

Building on the success of EP6, BHP then selected the bi-modal HDPE geomembrane again in 2024 for their EP7 evaporation pond at Olympic Dam, South Australia. This large-scale project covered over 700,000 m^2 (7,500,000 ft^2) and required a technically advanced, multi-layered geosynthetic lining system capable of containing aggressive mining tailings. The containment system included a double-lined 1.5 mm (60 mil) bi-modal HDPE geomembrane.

To ensure consistent performance across the containment system, a custom-engineered geonet and composite drainage layer was manufactured for the project. This drainage layer included the geonet being manufactured from a bi-modal HDPE resin, providing uniform chemical compatibility and mechanical integrity. To support electrical leak detection,of the primary top layer of 1.5 mm bi-modal HDPE, a patented conductive geotextile (Mills 2019) was laminated to the top surface of the geonet composite. The installation of the EP7 lining system was completed in 2025.

Figure 7. Photo of installed bi-modal HDPE in BHP EP7

Project Details:

- Owner: BHP Mining
- Evaporation Pond
- Location: Olympic Dam, South Australia

- Bi-modal HDPE Geomembrane (1.5 mm): 750,000 m² (8,070,000 ft²)
- Bi-modal Geocomposite Drainage Layer: 325,000 m² (3,497,000 ft²)
- Total Field Seaming: 98 km (60.9 miles)

6 Conclusion

The development of the bi-modal HDPE geomembrane spanned over five years and culminated in its commercial release in 2019. The material underwent rigorous internal and third-party validation including heat aging, chlorine and brine. This included chemical resistance, elevated heat aging, environmental stress cracking, and mechanical property testing. These efforts were documented in five separate technical publications throughout its development process. Since commercialization, the material has also undergone extensive testing at Queens University in Kingston, Ontario. This included a 3 year program where the material has undergone high temperature immersion testing to municipal leachates, perfluorooctanoic acid (PFOA) and chlorine. The material was tested for vapor transmission rates, environmental stress crack resistance, OIT retention and retained tensile strength.

The resulting new bi-modal HDPE material offers the industry a higher-performance solution for applications requiring superior thermal and chemical resistance. This material also addresses previous limitations associated with conventional grade HDPE materials, particularly in demanding environments such as mining, energy, waste and industrial containment.

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