Performance of polymeric geomembranes in different mining solutions

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ABSTRACT

Geomembranes are critical components in the design, construction, and operation of mining facilities such as heap leach pads, liquor ponds, tailings impoundments and waste rock facilities. Due to the nature of mining projects (normal stresses that may exceed 4 Mpa and very aggressive leaching solutions chemistries), the performance of geomembranes is pushed beyond the boundaries of typical liner designs and recommendations. Nevertheless, there is still a paucity of works in the scientific literature examining the performance of polymeric geomembranes in mining applications, particularly from the perspective of chemical compatibility. The present paper summarizes some of the mining work initiated at the GeoEngineering Centre at Queen's-RMC towards heap leach pads and tailings dams facilities. Results from an accelerated aging test program to evaluate the effect of low and high pH heap leaching solutions on the depletion of antioxidants from different polymeric geomembranes are reviewed, and the fundamentals of a pioneer aging study on tailings dams pore water are described.

1. INTRODUCTION

Geosynthetics have been widely used in mining applications where their primary function is to contain fluid migration. One of the major areas in which there has been a substantial development in the use of geosynthetics is the design of liner systems for heap leach pads and tailing dams. Examples of geosynthetics employed in such structures commonly include geomembranes, geotextiles, geosynthetic clay liners (GCL's), geonets and geopipes, depending upon the singularities of each application (J. F. Lupo & Morrison, 2007; John F. Lupo, 2008).

Heap leach pads consist of lined facilities onto which large piles of crushed mined ores are heaped and then irrigated with various chemical solutions capable of extracting valuable minerals (Thiel & Smith, 2004). Generally, single, and sometimes composite liner systems are used to minimize the release of solutions from the leach pad to the environment. Single liners usually comprise a geomembrane liner placed over a compacted liner bedding soil and may be adequate for areas that experience low hydraulic head or where the subgrade is of relatively low permeability. Composite liners comprise a geomembrane over a compacted clay or geosynthetic clay liner. For leach solution, pregnant liquor ponds and areas in the heap with a high head the liner system usually comprises a geomembrane, a geonet leak collection/drainage layer, and a second geomembrane on a compacted subgrade (John F. Lupo, 2010; Pries et al., 2014).

Tailing dams comprise engineered facilities that are built to confine slurried, thickened, paste or dry-stacked materials resulting from mining activities. As with heap leach pads, the conception of a liner system for tailing dams must incorporate the compatibility of several components, together with aspects regarding loading, hydraulic and operational conditions (John F. Lupo, 2008). The geomembrane liner materials applied to mining facilities such as heap leach pads and tailing dams are generally high density polyethylene (HDPE), linear low density polyethylene (LLDPE), polyvinylchloride (PVC), and polypropylene (PP), although HDPE and LLDPE are mostly common (Abdelaal & Rowe, 2017; Hornsey et al., 2010; John F. Lupo, 2010).

Physical and chemical exposures act as key agents in the polymer degradation, the latter being particularly critical for polymeric geomembranes (Hsuan & Koerner, 1998). According to Hsuan and Koerner (1998), the chemical degradation of high density polyethylene geomembranes can be divided into three stages, which are (1) antioxidant depletion, (2) a delay period during which polymer degradation effectively begins, although with no measurable impacts on its properties, and (3) intensified polymer degradation, which leads to changes in the bulk properties of the geomembrane such as stress-crack resistance, melt index (MI) and tensile strength, culminating in its nominal failure. The nominal failure of the geomembrane conceptually occurs when a particular property decreases to an arbitrary design level such as 50% of the initial value (Hsuan & Koerner, 1998).

The effects of different chemical solutions on geomembrane behavior and aging have been the subject of research at the GeoEngineering Centre at Queen's University for over 20 years. This range of work has predominantly dealt with the immersion of HDPE geomembranes in different leachate solutions derived from municipal solid waste (MSW) landfills (e.g. Abdelaal; Rowe; Islam, 2014; Ewais; Rowe; Scheirs, 2014; Rowe; Shoaib, 2017; Rowe; Abdelaal; Brachman, 2013; Rowe; Ewais, 2014; Rowe; Hsuan; Islam, 2008; Rowe; Islam, 2009). Little work has been published on the aging of geomembranes in mining solutions, for instance, Abdelaal and Rowe (2017, 2014) studying the effect of high pH mining solutions in a HDPE and LLDPE geomembranes, and Rowe and Abdelaal (2016) studying the aging of a HDPE geomembrane in low pH mining solutions.

This paper presents a summary of the chemical aging work with synthetic mining solutions at the GeoEngineering Centre at Queen's University, compiling some data published so far for synthetic heap leach solutions and briefly describing the chemistry work developed for the ongoing study with tailings dams pore waters.

2. ACCELERATED AGING AND MONITORING OF CHEMICAL DEGRADATION

Accelerating aging using immersion tests allow the assessment of a wide range of solution chemistries as well as different geosynthetics materials and temperatures in shorter times compared with more sophisticated tests. In this test method, geomembrane coupons are immersed in glass jars that are filled with a synthetic solution that simulates the leachate from mining facilities. The coupons are separated using 5-mm glass rods to ensure that the immersion solution is in contact with all surfaces of the coupons. The jars are then incubated at different elevated temperatures, e.g. 25°C, 40°C, 65°C, 75°C, 85°C and 95°C. High temperatures are used to provide data in a reasonable time, but they cannot be too high otherwise it may change the behaviour/characteristics of the immersion fluid, the geomembrane structure, or the degradation mechanisms. The samples are extracted at different incubation durations and the change in the geomembrane properties are measured with time.

Quantification of the three degradation stages for polymeric geomembranes involves monitoring different chemical, mechanical, and physical properties using a variety of index tests (i.e. measuring the change in properties of interest relative to the initial value of the virgin geomembrane). Typical geomembrane properties assessed at the GeoEngineering Centre at Queen's-RMC include, but are not limited to: standard oxidative-induction time (Std-OIT) (ASTM D3895) and high-pressure oxidative-induction time (HP-OIT) (ASTM D5885) through the differential scanning calorimetry principle, melt index (ASTM D1238), tensile properties such as yield and break strength (ASTM D6693), and notched constant tensile load stress crack resistance (ASTM D5397). To interpret this data, a technique known as Arrhenius modelling (Koerner, 2012) is commonly used to allow extrapolation of the geomembrane degradation to lower field temperatures based on the data collected at the higher temperatures.

Antioxidant depletion (Stage I) is usually evaluated in terms of the oxidative induction time (OIT). Quantification of Stages II and III is usually done by monitoring different polymer mechanical and physical properties. A change in melt index, for example, can be used to infer a change in the molecular weight as a result of cross-linking and/or chain-scission degradation in the polymer (Hsuan & Koerner, 1998). Stage III is usually indicated by a decrease in the notched constant tensile load stress crack resistance and/or the tensile break strength and strain of the geomembrane.

3. HEAP LEACHING ENVIRONMENT

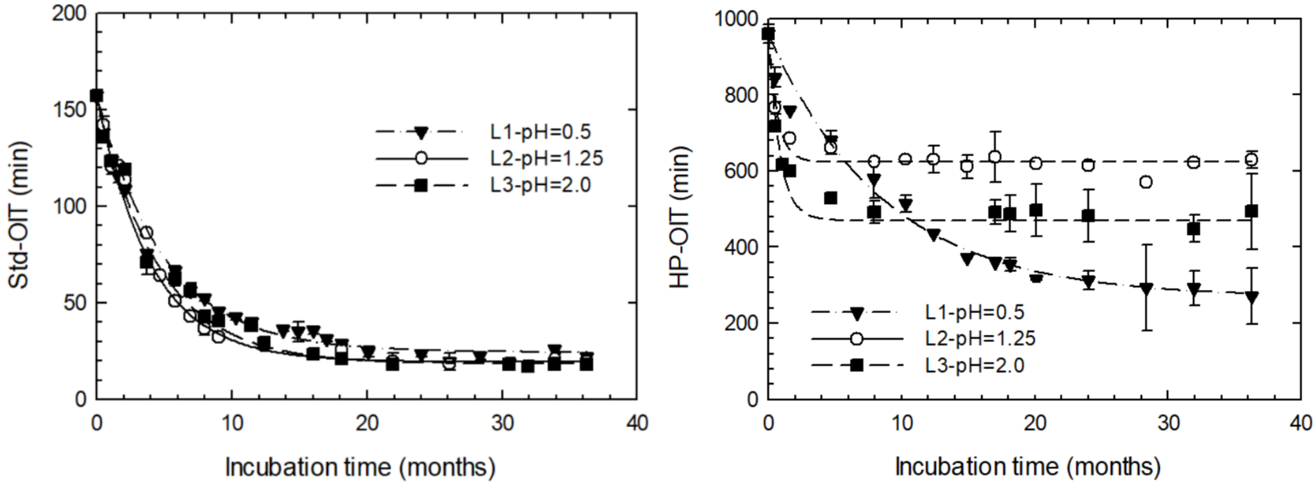
In order to investigate the chemical durability of different polymeric geomembranes in heap leach pads applications, an extensive study by the GeoEngineering Centre at Queen's-RMC was initiated in 2010. This investigation involved different thicknesses of LLDPE and HDPE geomembranes immersed in several extreme pH solutions, simulating the pregnant liquor solution (i.e. the leachate containing the metal to be extracted) of different heap leaching operations.

Rowe and Abdelaal (2016) reported results of antioxidant depletion from a 1.5mm HDPE geomembrane containing hindered amine light stabilizers (HALS) immersed in seven different low pH solutions, among which pH's of 0.5, 1.25 and 2.0 are highlighted herein. This pH range encompasses liquors found in copper, nickel, and uranium heap leach pads. The metal concentration for these solutions were high and were based on copper raffinate solutions. The authors found that the high concentration of metals in the pH 0.5 solution resulted in slower Std- and HP-OIT depletion than water at pH 0.5, suggesting that metals might inhibit the diffusion of antioxidants detected by both of those tests. Additionally, for the same metal concentration, decreasing the pH from 2.0 to 0.5 resulted in only a small change in the Std-OIT depletion. For HP-OIT tests, the fastest depletion rate was observed in pH 1.25, then 2.0 and 0.5 (Figures 1a and 1b, next page).

Leaching of gold and silver as well as the Bayer process used to produce Alumina (Al_2O_3) from aluminum bearing ores involves the use of highly alkaline leach solutions and that results in pregnant liquors with pH between 9 and 14.0 (Abdelaal & Rowe, 2017). Abdelaal and Rowe (2017, 2014) investigated the antioxidant depletion of different geomembranes in this high pH environment.

Abdelaal and Rowe (2014) investigated the antioxidant depletion from a 1.5mm LLDPE geomembrane in a solution with pH of 13.5 and compared the results to preliminary data obtained from the immersion of a 1.5mm HDPE geomembrane in the same incubation solution. Results showed that the depletion of antioxidants from the LLDPE geomembrane was slower than that for the HDPE geomembrane at the same temperature. The authors suggested that, for this particular case, the performance of the antioxidant package governed the depletion rates of the antioxidants more than the resin type (i.e.

whether LLDPE or HDPE), and that the antioxidant package used in the LLDPE geomembrane was better at resisting the depletion in the pH 13.5 than that used in that particular HDPE geomembrane.



a) Low pH, 95°C Std-OIT

b) Low pH, 95°C HP-OIT

Figure 1 - Variation with incubation time of (a) Std-OIT; (b) HP-OIT in low pH solutions at 95°C. Data points represent mean values and error bars represent the ±1 standard deviation. Adapted from Rowe and Abdelaal (2016).

Abdelaal and Rowe (2017) looked at the antioxidant depletion from the very same HDPE geomembrane used by Rowe and Abdelaal (2016) but in this case immersed in three high pH mining solutions, with pHs of 9.5, 11.5 and 13.5. They showed that the antioxidant depletion rate detected by Std-OIT tests was the fastest for the solution with pH of 13.5 followed by 11.5 and 9.5. For the antioxidants detected by HP-OIT tests, increasing the pH from 9.5 to 13.5 greatly increased both the antioxidant depletion rates and the residual HP-OIT values (see Figure 1, Abdelaal and Rowe 2017). This figure can be misleading if one simply looks at the early-time HP-OIT data (i.e. within the first 5 months), because it may suggest that the fastest HP-OIT depletion was for the solution with pH of 9.5 followed by 11.5 and 13.5. However, fitting the full 3-year data set including the residual values shows that depletion rates increases with increasing pH (see Abdelaal and Rowe, 2017, Table 5).

Ongoing work of the author of this paper includes investigating the changes in mechanical properties of the 1.5mm HDPE geomembrane used by Rowe and Abdelaal (2016) and Abdelaal and Rowe (2017) over longer incubation times (up to 90 months). This will provide a better understanding as to how the OIT values change at the onset of degradation, as well as whether the residual values detected by both Std- and HP-OIT tests provided any protection to the geomembrane.

4. TAILINGS DAMS

A pioneer chemical aging study with tailings dams pore waters was initiated by the GeoEngineering Centre at Queen's-RMC in 2019. This research effort examines HDPE geomembranes with different antioxidant packages immersed in four synthetic solutions that simulate the pore water chemistry found in different tailings impoundments. This study is particularly needed in the wake of the Mount Polley Tailings Dam failure (Canada), the Samarco Tailings dam failure (Brazil) and the Luoyhang dam failure (China). While none of these failures were related to the use of geomembranes, the fact that these failures occurred indicates that a more in-depth potential failure mode and effect analysis is required for those facilities. Any such analysis that reveals the failure of geomembrane liners due to stress cracking (e.g., Peggs et al., 2014) suggests a treacherous signal that could impact significantly on the environment and potentially on stability if it leads to piping of the underlying soil. However, the potential for stress cracking of different geomembranes in contact with typical mine tailings solutions has not been examined to date.

The distribution of metals and sulfate in the tailings pore water depends on the nature of the pore-water flow regime and particularly on the locations of the metal sources. For instance, the pore water near the surface of the impoundment is highly affected by sulfide oxidation and/or dissolution of minerals, therefore a moderately acid pH as well as high ion concentration is expected (Al et al., 2000). In deep saturated tailings without much dissolved oxygen (i.e. most likely near the geomembrane liner), sulfide minerals tend to be stable due to the reducing conditions and do not oxidize (Dold, 2014).

Thus, pore water pH remains around neutrality with decreased concentrations of metals and sulfate (Al et al., 2000; Lange et al., 2009; Lindsay et al., 2009; Othmani et al., 2015).

Conventional tailings impoundments are still the most common practice for most operating and proposed mines worldwide, which require construction and maintenance for the retention structures as well as management of an immense amount of water. However, the advances in dewatering technologies over the last years have presented designers with the opportunity of storing tailings in an unsaturated state rather than in the conventional "slurry-like" consistency associated with saturated conditions. These pre-filtered tailings are referred to as dry stacks (Amoah et al., 2018; Davies, 2011).

The literature on pre-filtered and dry stacks tailings is very scarce, being limited to cover practical insights and technical basis for the design of facilities (e.g., Lupo and Hall, 2011). To the best of the author's knowledge, no work has been published so far on the pore-water geochemistry of dry stack tailings, but it is expected that sulfide oxidation occurs at greater depths within the tailings, thus generating low pH pore waters in contact with the geomembrane liner.

Grounded in the aforementioned arguments, three synthetic tailings solutions were developed at the GeoEngineering Centre: a pH 4.0 solution based on the work of Al et al. (2000), simulating the chemical composition of pore waters from pre-dewatered sulfide-rich tailings; and two solutions with pH's of 7.0 and 8.0 based on the work of Lange et al. (2009), simulating, respectively, pH-neutral and moderately alkaline pore waters of saturated arsenic-bearing gold-mine tailings. On rare occasions, pH of saturated tailings seems to increase towards 10 due to the processing chemicals in the cyanidation plant (e.g. Craw et al., 1999). Thus, the heap leach mining solution with pH of 9.5 (Abdelaal and Rowe, 2017) has been added to the solution matrix of this work.

Current experiments conducted by the author of this paper include the investigation of OIT depletion detected by Std- and HP-OIT tests as well as changes in physical and mechanical properties of three HDPE geomembranes immersed in those four solutions. The geomembranes were incubated at 40°C, 65°C, 75°C and 85°C, so that the Arrhenius modelling technique can be used in the future.

5. FINAL CONSIDERATIONS

The present paper briefly reviewed the chemical aging work with synthetic mining solutions that has been done at the GeoEngineering Centre at Queen's-RMC. This extensive research effort can be divided into two major work fronts, namely, heap leaching and tailings dams.

Some of the heap leaching work published so far suggests that, for the 1.5mm geomembrane in study, the acidity from the low pH solutions as well as the high concentration of metals are somehow beneficial to the diffusion of antioxidants in the geomembrane, since antioxidant depletion rates detected by both Std- and HP-OIT tests were higher for water at pH 0.5. Additionally, decreasing the pH from 2.0 to 0.5 within the same metal concentration only resulted in a small change in the Std-OIT depletion. For HP-OIT the fastest depletion was for pH 1.25, then 2.0 and 0.5. Within the highly alkaline range, Std-OIT depletion rate was the fastest for the solution with pH of 13.5 followed by 11.5 and 9.5. For HP-OIT tests, increasing the pH from 9.5 to 13.5 greatly increased both the antioxidant depletion rates and the residual values.

The pH's of synthetic tailings pore waters fill the gap in the existing mining matrix at the GeoEngineering Centre: solutions with pH 4.0, 7.0 and 8.0 are introduced to simulate pore waters under oxidizing conditions (unsaturated pre-dewatered tailings or dry stacks) and reducing conditions (conventional saturated tailings). Considering extreme conditions in the mining industry wherein the performance envelope of geomembranes is being pushed beyond their typical limits, studies evaluating short and long-term changes in the properties of such materials under exposure to different chemical solutions are unquestionably necessary. As the demand for geomembranes continues to increase and the conditions to which they are exposed become more severe, it is important to minimize the potential risks of a failure long before there is any such failure so that the mining industry does not get caught by undesirable events.

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