GEOMEMBRANES IN MINING WORKS

A. Bouazza[1] and Y. Chen[2]
[1]Monash University, Department of Civil Engineering, Bldg.60, Melbourne, Vic. 3800, Australia;
Email:malek.bouazza@monash.edu,
[2]Zhejiang University, Institute of Geotechnical Engineering, Hangzhou 310027, China;
Email: chenyunmin@zju.edu.cn

ABSTRACT

The use of geomembrane liners in various mining operations is increasing rapidly. While they have not been accepted as readily as in the waste (landfill) industry, growth in the mining industry is occurring as operators begin to understand the advantages associated with the use of these materials. However, it is not a simple matter of transferring the technology from the tried and tested applications common to landfills, to the mining industry. This is primarily due to the extreme ranges in leachate properties generated from the various ore extraction processes, the harsh environment to which these materials are exposed and the extremely large normal loads they are subjected to. The paper gives a examples of lined facilities in Asia and discusses the performance of geomembranes in mining environments

Keywords: Geomembranes, heap leach, mining, tailings

INTRODUCTION

Mining is the backbone of many economies around the world. In many developing countries it provides more than 50% of the export earnings, for example in Papua New Guinea it represents 66% of the earnings (Fourie et al. 2010) compared to 42% in Australia (MCA, 2009). Therefore, it is not surprising that the mining industry is often found to be the single largest producer of solid waste around the world, sometimes orders of magnitude higher that other forms of solid waste (e.g. municipal solid waste). If one considers that in order to recover a gram or two of gold, one tonne of mineral bearing rock must be crushed and processed, and at least another tonne of waste rock is produced, an idea can be gained of the enormity of the waste management problem faced by the mining industry. In Australia, the annual production of mining waste is about 1.8 billion tonnes, which dwarfs the annual volume of municipal solid waste by a factor of about 120 (Fourie et al., 2010). Blight (2010) reported that the South African gold mining industry produced 740 000 tonnes of gold tailings in the decade from 1997 to 2006.

Considerable proportion of the mining industry has shifted to large scale open cut mining techniques which invariably require the removal of significant quantities of waste rocks. This is also coupled with a general trend of declining ore grades meaning that higher quantities of ore need to be processed to produce a given unit metal or mineral (Mudd, 2009). The use of geosynthetics in various mining operations is increasing rapidly. While they have not been accepted as readily as in the general construction market, growth in the mining industry is occurring as operators begin to understand the advantages associated with the use of these materials. For many of the applications such as load support and retaining structures the design and application is easily transferred to the mining field, albeit normally with far higher loading criteria.

When it comes to containment however, it is not a simple matter of transferring the technology from the tried and tested geosynthetics applications common to waste containment facilities such as landfills, where the information is widely available and well established, to the mining industry. This is primarily due to the extreme ranges in leachate properties generated from the various ore extraction processes and the harsh environment to which geosynthetic materials are exposed. Nevertheless, the rapid growth seen in the past decade in mining exploration and operation has led to a sharp increase in the use of a wide range of geosynthetic materials by the mining industry for all type of applications. Smith (2008) reported that from 1987 to 2008 more than 60 square kilometres of geomembrane liners were installed in heap leach pads alone. In addition to geomembranes which are extensively used in evaporation ponds, heap leaching and disposal of tailings (Breitenbach and Smith, 2006, Thiel and

Smith, 2004), other major liner applications include geosynthetic clay liners (Kim and Benson, 2004, Lange et al., 2007, 2009, Bouazza and Rahman, 2007, Shackelford et al., 2010), and geosynthetic capillary breaks in cover systems (Park and Fleming, 2006, Zornberg et al., 2010).

This paper concentrates solely on the containment aspects of geosynthetics in mining with particular focus on geomembranes.

GEOMEMBRANES

Geomembranes are flexible polymeric sheets mainly employed as liquid and/or vapour/gas barriers. They are designed as relatively impermeable liners and have been extensively used, over the past two decades, in barrier systems for waste containment facilities for a large spectrum of waste including mining waste. They have become critical components in mining facilities where their performance in containment of waste has been proven. These include base liners for heap leaching pads, liners to concrete basins and tank liners, solar (or evaporation) ponds for salt recovery, temporary exposed liners or "raincoats" for tropical sites, interlift liners in heap leach pads, liners for mitigation of acid mine drainage (AMD) from tailings or waste rock dumps and for tailings and process residues impoundments. Smith (2008) indicated that there is a strong correlation between metal production and geomembrane demand and that both are interrelated and driven by similar economic factors. Furthermore, he stressed the fact that this relationship is expected to continue and to be amplified with increasing use of heap leaching and diversified applications such as tailings and acid mine drainage control.

Heap leach facilities are probably the single biggest user of geomembranes in the mining industry, certainly in South America and the United States. In this process, crushed ore (which is usually first 'agglomerated' – the process of binding smaller particles into larger clusters) is transported (usually by conveyor) to an area that has been prepared with a geomembrane liner, above which are located a system of drainage pipes. These pipes are typically 10 to 15 cm diameter, spaced at about 2m centres. The agglomerated ore is often pre-treated with a solution (concentrated sulphuric acid in the case of copper) and then placed and spread on the geomembrane liner. Dilute sulphuric acid (at a concentration of around 2% and a pH of about 2) is then supplied to the surface of the agglomerated ore through either sprinkler irrigators, or a system of drip irrigators, the latter reducing evaporation rates quite dramatically. As the acid gradually percolates through the ore it dissolves the precious metal, producing what is known as a 'pregnant solution'. The percolation process may take a few weeks and the pregnant solution is recovered during this time and sent to a solvent extraction plant for metal recovery. As the product of mining in this case is the pregnant solution, it is imperative that losses through the underliner system are minimised (preferably eliminated) and recovery is maximised. A lining system below a tailing storage facility (TSF) will not have the same issues of ultra high loading common to the heap leach application, but issues of chemical compatibility with extreme pH solutions still exist, and appropriate compatibility testing programs are essential, as with any application of geosynthetics in critical conditions.

The liner materials typically used in these applications are high density polyethylene (HDPE), linear low density polyethylene (LLDPE), poly-vinyl chloride (PVC) and polypropylene (PP) geomembranes. HDPE, LLDPE and PP are also referred to as polyolefin geomembranes. Polyolefins are a group of hydrocarbons derived polymers that are based on a repeat unit of which ethylene is the parent hydrocarbon (hence polyethylene). The properties of polyolefins depend on the degree of crystallinity (i.e. density). PVC is synthetic thermoplastic polymer prepared by polymerization of vinyl chloride. PVC can be compounded into flexible and rigid forms through the use of plasticizers, stabilizers, fillers and other modifiers. Table 1 lists the geomembranes advantages and disadvantages. They are used, in most cases, as part of composite liners in which a geomembrane liner is placed over a compacted liner bedding soil, use as single liners or double liners is also possible in specific cases (Breitenbach and Smith, 2006).

Within the mining environment, geomembrane liners often become exposed to severe conditions which could affect performance of the liner. These conditions include high stress/strain levels, exposure to acid or basic process solutions, and harsh environmental conditions, such as ultraviolet radiation and high temperature extremes. Under these harsh conditions, the ability of the geomembrane liner to remain flexible and provide solution containment may become impaired. Use of HDPE geomembranes is therefore tending to become predominant due to their excellent resistance to solvents and chemicals brought about by their high crystallinity (40 to 60%); by comparison LLDPE geomembranes have an average of 15%-30% crystallinity whereas PVC geomembranes have 0% crystallinity and fPP geomembranes about 5% crystallinity. Furthermore, HDPE does not possess any functional groups in its structure which favour potential chemical attack. Chemical attacks can be detrimental to the longevity of the geomembranes. Highly crystalline polymers, such as HDPEs, tend to be rigid, high melting and less affected by solvent penetration. Crystallinity makes a polymer strong, but also lowers its impact resistance and increases its susceptibility to environmental stress cracking; whereas, a decrease in polymer crystallinity as in the case of LLDPE relative to HDPE, is associated with decreasing mechanical stiffness and chemical resistance (Scheirs, 2009). When assessing the performance of geomembrane liners under harsh mining conditions, it is important to view the performance life in terms of the life of the mine. Mining facilities often have a life on the order of 10 to 50 years, after which the mine is reclaimed to minimize environmental impact and to promote long-term environmental stability. Whereas it is difficult to assign a life to geomembrane liners in these environments, experience from actual mines in continuous operation for nearly 20 years, has indicated these materials are resilient and able to perform as designed.

Table 1 Advantages and disadvantages of commonly used geomembranes (Bouazza, 2010, modified from Scheirs, 2009)

Geomembrane	Advantages	Disadvantages
HDPE	• Broad chemical resistance • Good weld strength • Good low temperature properties	• Potential for stress cracking • High degree of thermal expansion • Poor puncture resistance • Poor multiaxial strain resistance
LLDPE	• Better flexibility than HDPE • Better layflat than HDPE • Good multiaxial strain properties	• Inferior UV resistance to HDPE • Inferior chemical resistance to HDPE
fPP	• Can be factory fabricated and folded so fewer field fabricated seams • Excellent multiaxial properties • Good conformability • Broad seaming temperature window	• Limited resistance to hydrocarbons and chlorinated water
PVC	• Good workability and layflat behaviour • Easy to seam • Can be folded so fewer field fabricated seams	• Poor resistance to UV and ozone unless specially formulated • Poor resistance to weathering • Poor performance at high and low temperatures

Geomembranes in Heap Leach Pads and Containment Facilities

Heap leach pads are generally constructed utilizing as much as possible the natural topography of the site in a variety of climates ranging from arctic (temperatures as low as -30^{o}C), tropical wet (rainfall exceeding in some cases 2.5 m/y) to dry Saharan climates (temperatures as high as +50^{o}C) and at altitudes above 4000 m (High Andes of South America). The pad area is cut and filled as required, and trimmed to achieve a desired slope of 0.5 to 1%. HDPE or LLDPE are normally used for the base of the pad with the liner being between 1-1.5 mm thick over the pad and between 2 - 3 mm thick in the sumps and drains. Directly over the liner are installed (generally HDPE) drainage pipes, which are coved by a layer of about 60 cm granular protective soil layer to protect the geomembrane liner-pipe system during ore stacking. Contrary to the practice in the landfill industry, geotextile protection layers are seldom used in heap leach pads.

The geomembrane lining material is used to retain chemical solution used to dissolve minerals from ore, and to allow the leachate to be collected and refined. Heap leaching presents a combination of extreme base pressures and high moisture/acidity conditions on the geomembrane not present in any other containment application. These extreme conditions push the envelope of known geomembrane performance often beyond the recommended general design limits, including 150-180 m high heaps, equipment loading of up to 53 tons per wheel, coarse rock overliner, concentrated acid exposure, hydraulic heads of up to 60 m, liquefaction potential and harsh arid climates with daily temperature extremes (Thiel and Smith, 2004). The combined action of sulfuric acid and temperatures reaching 70°C on an exposed geomembrane surface can seriously soften most liner materials. Furthermore the dumping of ore on the liner necessitates a strong membrane that is resistant to abrasions and punctures. Finally the steep, angular design of the collecting ponds requires a strong, durable product. For lined mining facilities subjected to moderate to high loads (greater than 300 kPa), geomembrane materials such as HDPE, LLDPE, and (to a lesser extent) PVC are used, mainly because of industry experience with these materials and documented performance from constructed mine facilities. However, geomembrane-lined heap leach facilities are being designed with ore heights approaching 200 m, resulting in normal stresses in excess of 3.3 MPa (Lupo and Morrison, 2007) presenting, in this respect, new challenges to the geosynthetics industry.

Mining waste comes in one two primary forms: waste rock and tailings. In any mining operation, in order to access the valuable, mineral bearing rock, it is first necessary to strip or excavate non-mineral bearing rock. This rock, which has been fragmented during the drilling, blasting and excavating process, is dumped in dedicated storage areas, known as waste rock dumps. Tailings on the other hand are the by-product of the crushing, milling and chemical extraction process used to recover the valuable mineral being mined. Tailings are generally sand sized or finer, and are managed by pumping at low solids contents and depositing into purpose-built impoundments, known as Tailings Storage Facilities (TSFs). The storage of these very large volumes of waste rock and tailings results in storage facilities that cover very large areas of land. Some of the oil sands TSFs exceed 100 hectares, and areas exceeding 120 hectares are not uncommon in base metal, gold and platinum mining operations (Fourie et al., 2010). Solid tailings are in most cases mixed with water and pumped to the tailings storage facility (TSF), sometimes over large distances (in excess of 5km). Upon deposition, large volumes of water separate out from the solid material, and this water must be stored and managed in such a way that it poses no risk to the environment. Unlike landfills where the leachate head on the underlining system is restricted, usually to around 0.3m., the hydraulic head acting on a TSF liner system can be several meters. TSFs are increasingly lined to minimise the possible contaminants migration. Dillon et al. (2004) provide an insight on the largest fully lined (geomembrane + GCL) tailings storage facility in Europe located in Ireland. Lupo (2009) indicated that several TSFs have been lined in USA. Fourie et al. (2010) indicated that bauxite residue disposal sites, where the very high pH and salt load of the leachate, often coupled with the proximity to residential areas, has resulted in mining companies such as Alcoa World Alumina and BHP-Billiton voluntarily implementing the installation of lining systems.

Example of Lined Facilities in Asia

Site 1 TSFs, Gold Mine, China (Gassner and Wrench, 2008)

A gold mine was established in the Gobi desert in Qinghai Province, China at 3,700 m above sea level and where severe cold weather conditions are experienced during the winter months. A tailings storage site was selected about 1 km from the process plan and 500 m from an ephemeral river that is located in the valley. Testing of the tailings showed that it was a type II waste according to the Chinese regulations GB 5085 “distinguishing standards for hazardous waste” (i.e waste contains pollutants with concentrations in excess of the limiting criteria). Type II sites require either a compacted clay liner or a geosynthetic liner.

A geotechnical investigation revealed that the surface soils would not be suitable for constructing a compacted clay liner, and the near surface soils included a high proportion of gravel, pebbles and cobbles. A design was therefore prepared including a composite liner consisting of a geosynthetic clay liner (GCL) and a 1.5 mm HDPE geomembrane (Fig. 2). The purpose of the GCL was to provide a reliable cushion layer below the geomembrane to protect the geomembrane from damage by the coarse subgrade once the liner was loaded by the tailings. The second function of the GCL was to improve the advective performance of the liner system to reduce the risk of contamination of the nearby water resource. The extreme weather conditions in this remote part of China offered additional challenges in the installation process that needed to be addressed to ensure a satisfactory outcome of the works. Geosynthetic liner systems provided a valuable environmental protection system for a remote site where local materials did not meet lining engineering requirements.

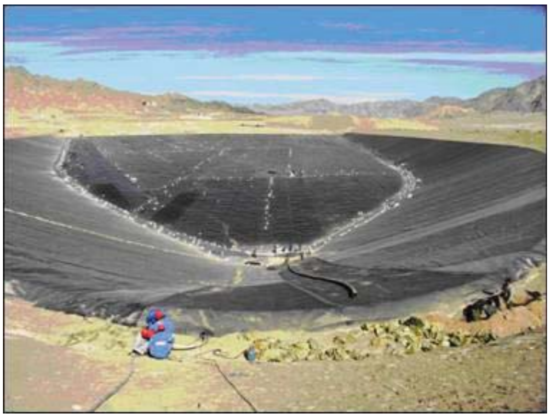

Fig. 1 HDPE geomembrane liner, TSF Gobi Desert (Gassner and Wrench, 2008).

Site 2 Heap Leach, Zijin Hill gold-copper mine, China

The Zijin Hill mine is situated in Tongkang Valley, on the west side of Xinwuxia Dam, Fujian province, South-Eastern China. It is located in the middle and lower reaches of Tongkang creek-a tributary of the Tingjiang river. The valley with an "U" shaped cross-section extends along the east-west direction. The hillsides slopes gradients on both sides of the creek range from 25 to 35°, and slope stability as well as the vegetation development are quite good. The west side of the heap leach pad is about 600 m away from the Tingjiang riverbed.

The heap leach pad covers an area of 35×10^4 m^2. Currently, the total volume of the stocked ore is estimated to be approximately 14000×10^4 m3, and the top elevation is up to about 279m. However, the standard of the current liner system is relatively poor, and it is difficult to meet the seepage regulatory requirements. Urgent re-design and construction of a new liner system was needed.

The liquor collected from the heap leach was found to have a pH ranging from 0.89 to 2.4 and a copper concentration varying from 120 to 1090 mg/L which can be classified as hazardous liquid according to Chinese regulations GB5085.1-2007 (identification standards for hazardous wastes-identification for corrosivity) and GB5085.3-2007 (identification standards for hazardous wastes-identification for extraction toxicity).

Very limited design specifications for heap leach pad liners design exist in China. In most cases, the detailed technical design requirements for hazardous waste landfill and disposal project construction (CCICED [2004] No.75) and the technical code for liner system of municipal solid waste landfill (CJJ113-2007) are adopted for the design of heap leach pad liners. Furthermore, the design needs to comply with Chapter 6 of the standard for pollution control on hazardous waste storage (GB18597-2001). Figure 2 shows the lining system adopted for the Zijin Hill heap leach pad liner

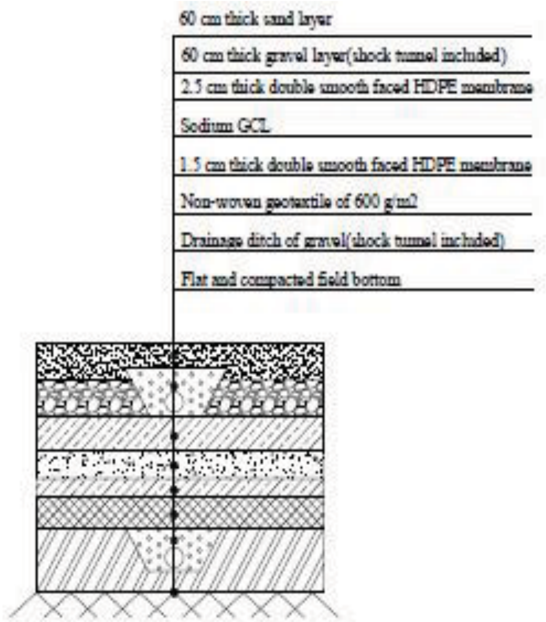

Fig. 2 Zijin heap leach pad lining system

Site 3, Heap leach, Boroo Gold Mine, Mongolia, (Ng and Qi, 2012)

The Boroo open-pit gold mine site is located in Mongolia at the west of the capital city Ulaanbaatar . The mine site is situated in mountainous terrain with average elevation of 1,600m above mean sea level. It has a mid-continental climate, temperate to cold, with an average annual temperature of approximately 0ºC. Temperatures may drop to -40ºC during the months of December through February. Summer temperatures may exceed 40ºC, but they average approximately 20ºC. The area receives about 25 cm of precipitation per year, most of which is rainfall between July and August. The winters are relatively dry, with a moderate amount of snow from early November to April. About 330,000 m^2 of polyethylene geomembrane were used to line the heap leach pad. HDPE geomembrane was used for the solution ponds (Fig. 3) and LLDPE geomembrane for the heap leach pad system (Fig. 4). Textured HDPE geomembrane was used on the slope to enhance the overall slope stability of the heap leach pad system.

Fig. 3 HDPE geomembrane lined chemical solution pond (Ng and Qi, 2012).

Fig. 4 Heap leach pad system lined with LLDPE geomembrane (Ng and Qi, 2012)

CONCLUSIONS

The purpose of incorporating geomembrane liners into a modern mining operation associated with either protection or production is to reduce the potential for environmental risks associated with contaminant migration offsite and to improve the recovery of mine waters either for re-use or to extract the product that is in solution. Regardless of the ore, process wastewaters and leachates having strongly alkaline or strongly acid pH as well as elevated temperatures are the greatest threats to their long term performance. Degradation of antioxidants can be of concern for the long term performance of polyolefin geomembranes such as HDPE or loss of plasticizers in the case of PVC. Excessive temperature increases the rate at which these adverse reactions occur, but also directly affects geomembrane strength and elongation. Design criteria must adequately assess and address the potential for chemical and thermal degradation.

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