GEOMEMBRANES USED IN HEAP LEACH SX-EW MINING: A MANUFACTURER'S PERSPECTIVE

Mauricio Ossa Defilippis, SL Limitada, Santiago and Antofagasta, CHILE

ABSTRACT

To talk about Geosynthetics in South America is not possible without linking them to the overwhelming development of the Copper Mining industry in Chile, nowadays the biggest copper producing nation worldwide. Between 1990 and 2005 the production of copper has increased from 1,400,000 tons to 5,400,000 tons per year. At present, after 15 years of continuous developing of the mining industry through the exploration for new deposits, the persistent improvement of the mining technology and the closure of those sites where the resources has been already exhausted or are become economically nonviable, has aroused a new reality that have to be faced; the environmental impact beyond the active life of the mine. In all these stages the geosynthetic industry has played a major roll, providing suitable materials for use in such projects around the world.

This paper focuses on geomembranes used for heap leach mining technology. Applications include but are not limited to barriers for pads, pounds, channels, tanks, collectors, and in-plant containment.

BACKGROUND

Leach pad technology was born and patented in North America the year 1975. Coincident with this in Chile, a medium size Mining company, "Sociedad Minera Pudahuel" started a technique to develop deep repercussions in the extraction of copper from the ore. This development consisted mainly of the improvement of large scale Thin Layer Leach Pads. At the end of the 80's "Lo Agirre" a new Copper Cathode Plant, started operations using the TLLP technology combined with the Solvent Extraction process and Electro Wining Cathode Extraction (LX - SX - EW). This plant was the very first one to apply at commercial scale the Thin Layer Leach Pad Technology. During the next two decades this process reached global importance.

In contrast, the solvent extraction process was developed during the Second World War by the United States in order to obtain the uranium required for the Manhattan Project. Later, this technology was declassified and brought to service in the civil industry, particularly to the copper mining industry.

The Heap Leach Solvent Extraction - Electrowining Technology - (SX-EW) at a glance. A description of the heap leach SX-EW process, from the crushing and stacking operation to the electrowinning of copper cathode, is explained below.

Crushing

Ore from the mine (ROM) is delivered to the stockpile and placed in designated stockpiles to segregate ore on the basis of ore type and grade. This ore is fed to the crusher by a Caterpillar type front-end loader. The crusher could be a two or three stages process after which the crushed ore is conveyed to the agglomeration area.

Agglomeration

The agglomeration process is intended to minimize segregation of the coarse and fine components of the ore in a heap, so that reduces short-circuiting of leach solutions in the stacked heap, and creates a uniform wetting pattern over the leaching ore.

Concentrated sulfuric acid is added to the ore at a typical rate of 10 kg/t, via a spray bar at the feed end. Water or leach solution is also added through an adjacent spray bar to achieve approximately 8% total moisture. The addition of acid to the ore before irrigation ensures that the total acid requirements of the leaching process are partially satisfied. The acid has to dissolve the copper as well as other acid soluble materials. This other non-copper acid soluble material is called “gangue”. It consumes acid without generating additional copper.

The Pad Construction

The heap leach pads are constructed, utilizing as much is possible the natural topography of the site. The pad area is cut and filled as required, and trimmed to achieve the desired slope of 0.5 to 1%. Other earthworks, including perimeter bund walls, interior drainage ditches and leak detection drains, are formed prior to final watering and rolling. The completed pad is then inspected in detail and any imperfections are rectified, before the geomembrane is installed.
The base of the heap consists of a geomembrane liner. High density polyethylene or Linear Low density (HDPE or LLDPE) lining material is used throughout. The liner is between 1 mm and 1.5 mm thick over the pad and between 2 mm and 3 mm thick in the sumps and drains. Directly over the liner are installed the HDPE drainage pipes, and then a granular protective soil layer about 60 cm thick is placed directly over the geomembrane-pipe system, to protect the liner during the ore staking.

The agglomerated ore usually is delivered to the leach pads by overland and modular conveyors to a final radial stacking conveyor which is capable of stacking ore up to 8.5 meters high. One of the most used stacking method is called radial stacking, and involves the ore being placed in layers approximately 200mm thick, leaving a level surface on top of the heap.

Figure 1. Protective layer installation in a heap leach.

Figure 2. View of the collection system in a heap leach.

Staking and Heap Construction

For sulphide ore, there is a forced aeration system that supplies low pressure air to the base of a heap, which helps to promote bacterial oxidation reactions in the heap. The air lines are the same or similar as those used for drainage, namely 100mm slotted drainage pipe. These are installed during stacking across the face of the heap at a height of 1 m above the surface and at 2 m centers. For the oxide ore, no aeration is needed and just the drainage pipes are installed.

Irrigation

The piping network for each heap comprises main lines at ground level and heap supply header pipes along the heap, which distribute solution over the surface of a stacked heap through a series of either dripper lines or sprinklers. All piping networks are HDPE throughout, and are installed manually or using special equipments. Once irrigation process has started the solution percolates down through the entire heap until it reaches the impermeable polyethylene geomembrane base of the leach pad. The pad is built on a slight slope towards a series of solution drains. This causes the solution to flow towards these drains once it has reached the geomembrane barrier at the base of the heap. Oxide ore is generally leached at irrigation rates between 4 to 8 L/hr/m2. Sulphide ore is leached between 7 to 15 L/hr/m2. Aeration of sulphide ore is continued through the lifespan of the heap.

In a two-stage leach operation, the barren solution from the solvent extraction plant ("raffinate") which has a high acid concentration, is fed to those heaps that have been leached to greater than 50% copper recovery. The solution exiting these heaps, called "intermediate leach solution" or ILS, becomes the feed to those heaps from which less than 50% of the copper has been recovered, which then produces "pregnant leach solution" or PLS suitable for solvent extraction recovery. This flow regime is regulated according the existing conditions by directing each individual heap effluent stream to either the PLS, ILS or Raffinate drains to control pond levels and solution grades.

Figure 3. Detailed view of the irrigation system in a heap leach.

Solvent Extraction

The objective of the SX plant is to produce a pure copper sulphate solution suitable for the Electrowinning process. A simplified flow diagram of the leach and SX circuit is illustrated in Figure 4.

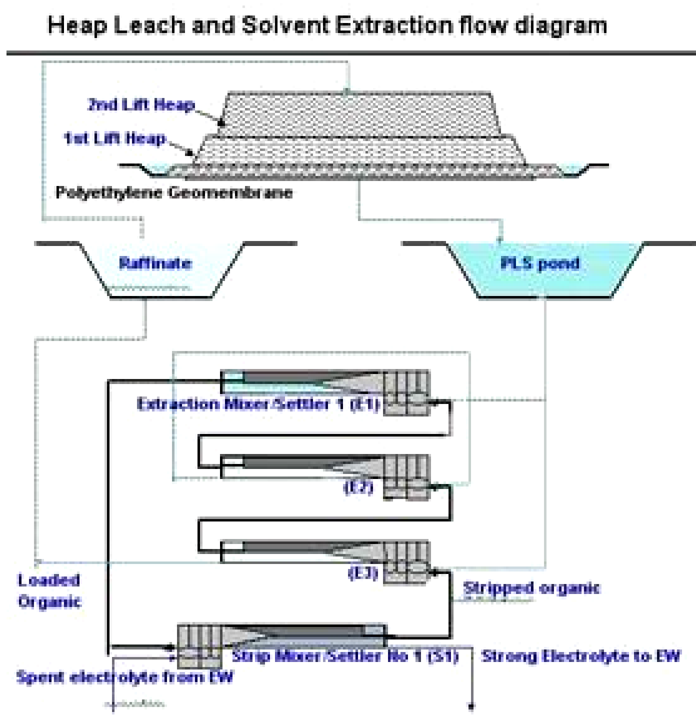

Figure 4. Heap leach and SX flow diagram.

Pregnant Leach Solution (PLS), containing between 1.5 to over 8g/L copper is contacted with an organic copper extractant, LIX984N; which has been diluted with a low volatility kerosene based carrier (diluent), in a two stage mixing tank. The immiscible aqueous and organic phases form an emulsion in the mixer (also known as the "organic"), which allows for extremely efficient surface contact. Copper in the PLS is extracted into the organic phase during this contact by an ion exchange reaction.

The emulsion then flows into a settler where the two phases separate as they flow towards separate discharge launders. A typical mixer/settler is shown in Figures 5 and 6. The aqueous phase, stripped of copper, is now called Raffinate and discharges to the Raffinate pond where it will be returned to the leaching operation as leach solution. The organic phase, now loaded with copper, discharges to the loaded organic storage tanks. From here it is pumped to the strip stage mixer/settler.

Figures 5 & 6. Two different views inside the Solvent Extraction area.
The walls and the floors are lined with studded HDPE liner.

In the strip stage the loaded organic is contacted with spent electrolyte solution which has been returned from the EW tankhouse. This solution contains 35-40g/L copper and 180g/L sulphuric acid. The spent electrolyte strips (removes) the copper from the organic phase into the aqueous phase during contact in the mixer. The strip reaction is the reverse of the extraction reaction. The stripped organic is then separated from the electrolyte in the settler and discharged from the strip settler to the extraction stage mixer/settler where it is again contacted with PLS to extract more copper. The electrolyte is now called strong electrolyte and contains 45-55g/L copper and 160g/L acid.

The strong electrolyte is almost ready to be pumped into the EW tankhouse, but first it has to be thoroughly cleaned of any organic carryover (entrainment) and fine solid particles, both can of which lead to problems in the electrowinning circuit.

Electrowining Operation

The EW circuit has to produce a high purity copper cathode at high current densities and maintain good current efficiency.

Strong electrolyte leaving the discharge launder of the strip stage settler is passed through two separate stages of filtration before it reports to the tankhouse. First it is pumped into a Jameson flotation column, where any entrained organic is coalesced on tiny air bubbles and rises to the top of the column. The recovered organic is purged off within a layer of froth. The electrolyte is then pumped through Spintek multimedia filters. The filter medium consists of layers of anthracite, garnet and coarse sand, and is very effective in removing fine suspended solids and any entrained organic not removed by the Jameson column.

The strong electrolyte passes through a heat exchanger where the solution temperature is raised to around 35 deg. C by the spent electrolyte returning from electrowinning tankhouse. Once heated the electrolyte reports to the scavenger electrowinning cells. The electrolyte leaving the scavenger cells reports to the circulating electrolyte tank, which is joined to the spent electrolyte tank. The circulating electrolyte is pumped to the remaining conventional cells before returning to the spent electrolyte tank. The spent electrolyte is pumped to the strip stage mixer/settler to return as strong electrolyte.

Each electrowinning cell contains many stainless steel ISA Process cathode plates and a similar number of lead alloy anodes. Scavenger cells are identical to the conventional cells except that they receive flow from the solvent extraction circuit first. They remove any remaining solids or traces of entrained organic that may have passed through the filtration stages, and hence they protect the remaining cells. As electrolyte flows through the EW cells, DC power is applied to the anode/cathode electrical circuit. Under these conditions electrochemical reactions occur. The lead anode transfers electrons across to the cathode in an even dispersion pattern. As copper metal is plated, acid is produced which is then used to strip copper out of the loaded organic in the solvent extraction strip stage leading to a continuous recirculating circuit.

Figure 7. View of the Pump Station in PLS pond.

The Geosynthetics along the Heap Leach Technology

The heap leach technology makes an intensive use of the geosynthetics materials since the very beginning of the process and in every stage of it. Geomembranes, Geopipes, Geotextiles, Geonets and Studded Concrete Liners have a very important roll. They are used intensively lining millions of square meters.

Though the geomembranes are the most important component in this myriad of polymers products because they are used in the most extended component of the system, the rest of the geosynthetics materials play a significant roll. Following the same order it was used in the Heap Leach process described formerly, it is possible to enunciate several important issues.

Heaps: The base layer of the Heaps is lined by a geomembrane, usually a Polyethylene liner (HDPE or LLDPE) with thickness of between 1.0 mm and 1.5 mm. The geomembrane could be smooth, single side textured, double side textured, or a suitable combination according to the design parameters like the seismic activity of the site, slopes, topography etc.

Conveyor Channels: The leaching solution collected by the geomembrane is diverted by means of proper disposed open channels that are fed along the pad and though the main collectors disposed in the downstream extreme of the heap. The channels are commonly lined by a thicker HDPE geomembrane and their content goes directly to the main HDPE Pipe Lines which finally discharge the leaching solution to the ponds area (ILS or PLS).

Figure 8. View of drainage systems in a heap leach.

Figure 9. View of the collector channel in a unlined heap leach.

ILS and PLS ponds: These units are compounded for the whole geosynthetics product collection. Commonly the lining system consist in a double HDPE liner 1.5 mm thick, that sandwich a drainage layer based in a HDPE geonet connected to a shaft intended as a leak detector. Sometimes the secondary liner is protected from the soil surface by means of a 400 g/m^2 nonwoven geotextile. Some projects additionally consider that the PLS be also provided of a floating cover in order to keep the solution free of contaminant particles that can affect the quality of EW process. These ponds also are provided of a huge pump station that has to be lined with studded concrete liner in order to resist the pump suction generated here.

Raffinate pond: The conditions here are quite similar to the ponds mentioned above. However here never a floating cover is needed but skimmers specially designed for the recovery of the organic. Sometimes the liner used here is 2 mm thick as the organic tend to swell and permeate the geomembrane.

Figure 10. View of the Raffinate Pond.

SX areas: these areas are compounded by a series of concrete pond trains lined with very thick HDPE geomembrane liners, 3 and 5 mm depending if they are going to be used at the bottom or on the walls were they get contact with the organic solution.

Tank farm: The Tank Farm is formed by many big and deep concrete tanks, lined commonly with Studded Concrete Liners and located into a depressed area also lined and able to serve as a secondary containment area.

Figure 11. View of one component of the Tank Farm area.

EW Plant: The Electro Wining building is more like an industrial plant where the protection provided for the geosynthetics materials rather a protective floor layer than a containment liner. The aisles are lined by rugged and thick HDPE membranes, meanwhile others areas subjected to damage by spill of acid solution are lined using reinforced PP.

The Manufacturer Point of View

So far, this paper has presented a general description of the geosynthetics used in the mining industry, particularly of those used in the heap leach technology. The following addresses concerns of manufacturers such as SL Limitada (SL).

Figures 12 & 13. The spark test detector (right) can't help when the liner is not properly installed or deployed (left).

SL is aware that most processes in the mining operation require many years of almost uninterrupted service. Heap leach Technology is not complex but rather results in many different extreme situations, and each must be considered individually and then as part of an entire system. Polyethylene geomembranes (HDPE and LLDPE) have proven to be the best and most reliable product on the market and they have served under the harshest conditions in the mining industry with an unmatched record of effectiveness and endurance for almost 40 years. However polyethylene geomembranes need to be complemented with:

- The knowledge of the product by the designer (properties, strong points and weak points).
- An experienced CQA company that controls the installation process and feedback the design.
- A clear and wise specification that requests no more or less than what is needed.

The following text will show why SL believes that beyond the quality of the product, these three points always have to be present in any project. We will show each part using geomembranes in a heap leach system, the respective aggressive conditions, and then the considerations to work around the concern.

Conditions that will lead the choice of the proper geomembrane in a heap leach operation.

Pad Area Immediately Under the Heap: This area has to support the huge masses of ore formed by staking many levels (static heap), each one about 7 meters high or just one level (dynamic heap) where the liner is continuously stressed by the loading and unloading process achieved by huge mobile equipment. Moreover the aggressive solution constantly irrigated throughout the pad is going to be acting and leaching the ore and the antioxidants of the geomembrane so that the liner endurance has to rely essentially on the quality of the resin and in the geomembrane thickness.

Under such circumstances, some critical properties that arouse concern are: environmental stress cracking, minimum thickness and not puncture resistance but the ability to endure those forces that tend to perforate the geomembrane. SL strongly believes that this fine point is critical and can not be overlooked. Puncture force is not directly related to the energy required to puncture a geomembrane.

Immediately out of the pad area, there are channels that collect the leachate and stresses are almost negligible, but there is the huge solar radiation over the desert, constant flow of the acidic leachate conveyed to the ponds, and elevated temperature. As in the heaps, antioxidants will be leached from the polymer resins. To protect the liner under such circumstances carbon black and the antioxidant package will be the most effective barrier against the UV degradation and the resin type will be the most decisive property to guard against attack of the different chemical agents. In the same way, the minimum thickness plays an important roll and therefore must be considered in pad design.

PLS & ILS Ponds: These units play a critical roll in the heap leach technology as they are constantly sending and receiving solution. These ponds need to be designed with a very high factor of safety. They can not be taken off line. They are critical path elements designed to endure the whole life span of the project with minimum maintenance. Their design relies on the impermeably of the system rather than the impermeability of a single material. A double liner system is used consisting of a geonet layer sandwiched between the secondary and primary geomembrane, where the geonet is connected to a detection shaft at atmospheric pressure so that any leak to the primary liner goes directly to the detection shaft where it should be pumped out as soon as possible in order to keep the atmospheric pressure condition into the drainage layer. In addition, the “pump station” built on concrete needs to be accommodated. Connections between stiff and flexible areas are always a challenge. As matter of fact, most defects are found on these ponds (extrusion weld) between the pond liner and the pump station liner as a result of the following:

- The welding has to be achieved in areas where there is not enough room to handle the welding equipment (grinders, hot air guns, extrusion welders) or the QC/QA equipment (vacuum box).
- There was an improper grinding and preparation of the surfaces to weld.
- The welding process was achieved when the geomembrane was still expanded, causing stressed areas and trampolines.

A PLS pond recently evaluated because persistent leaks existed over time, shows all the above conditions. The geomembrane (HDPE 2 mm thick) was evaluated making a laboratory test analysis. The liner was about four years old. The results were outstanding, with the liner still retaining almost 90% of the mechanical resistance and flexibility.

On this example the most significant properties of the liner were:

- Its resistance to the stress cracking failure.
- The minimum thickness.
- Carbon black content and dispersion.
- Integrity endurance.

<u>The Raffinate Pond</u>: This unit shares similar conditions to the PLS and ILS ponds; however it has an additional concern of heightened organic content. The organic which is a solution of copper extractant, diluted with low volatility kerosene based carrier, can swell the polyethylene liner and eventually make it almost unweldable and therefore difficult to repair. When a rafinate pond fails, commonly the whole liner system needs to be reconstructed at great expense, therefore good CQA supervision and a conservative design for this area is strongly recommended.

<u>SX, Tank Farm and EW Areas</u>: Although all are different units, they all are mostly concrete structures lined with heavy HDPE liners (between 3 and 5 millimeters thick), studded concrete liner or simple HDPE plates. Therefore almost all the seams are extrusion welds. Whenever there is a failure or a leak, the reason is associated with a poor quality installation or an unpractical design. Commonly these structures, for economic reasons consist of just a single liner, therefore the acidic liner leak goes directly on the concrete attacking and degrading the structure. The dissolved concrete then could clog the leak detection devices making it inoperative. The consequences could be serious. The inner area between the liner and the concrete is communicated with the containment system. If the acidic solution occupies the same level on both sides, degradation to the underlying concrete and the steel structures could be swift and significant.

Making the geomembranes to specification.

It is critical that the geomembrane performs well over extended period of time in these extreme conditions. Poor geomembrane performance can result from a geomembrane that has not been manufactured to a good specification such as GRI-GM13, and installed with an effective CQA program.

The standard tests that are performed in the geomembrane industry commonly are:

1. Thickness, according to ASTM D5199
2. Tensile test, according to ASTM D6693
3. Tear resistance, according to ASTM D1004
4. Puncture resistance, according to ASTM D4833
5. Carbon black content, according to ASTM D1603 or D4218

6. Carbon black dispersion, according to ASTM D5596
7. Density, according to ASTM D1505 or D792
8. Stress crack resistance, according to ASTM D5397 (NCTL)
9. Oxidative induction Time, according to ASTM D3895 / D5885
10. Oven aging, according to D5721 and D3895
11. UV Resistance, according to GM11 and ASTM D5885
12. Delamination, according to in-house procedures.

However, some properties are more important than others.

Tests numbered 2 (tensile), 3 (tear) and 4 (puncture) are mechanical index tests whose results cannot be interpreted for a final design. We can not deduce that geomembrane A will endure bigger deformations than a geomembrane B, based on the results of tensile or tear tests. Therefore, the puncture test is a partial answer for most geomembrane applications as it considers just the force needed to puncture the geomembrane. A very significant part, but for practical reasons dismissed, is the deformation during the test. Both values combined would give the energy needed to puncture the liner (see Figure 14) what could be very important comparing two different liners. It is suggested that material should be evaluated for puncture elongation and strength.

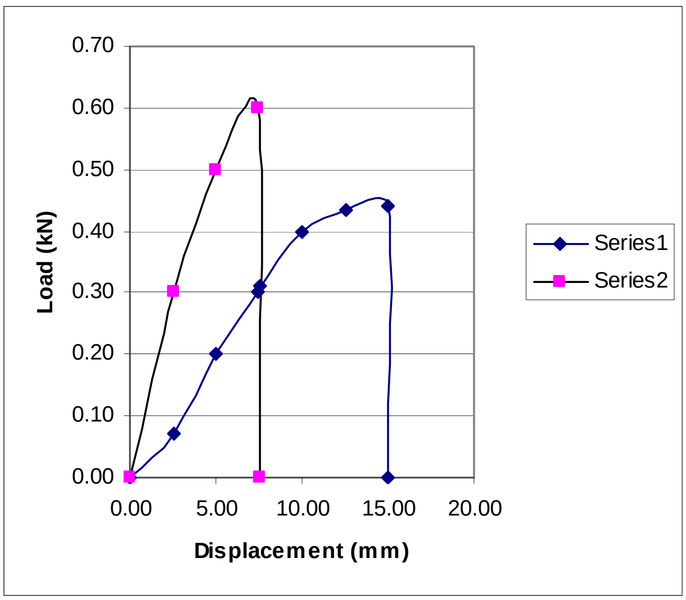

Figure 14. Curves obtained from the puncture test.

Test 7 (Density) gives part of the fingerprint of the resin and therefore is useful, usually well behaved and understood. It is important in regard to diffusion and chemical resistance. This property will also reflect the general classification of the geomembrane.

Tests 1 (Thickness), 5 (CB content), 6 (CB dispersion), 8 (stress crack), 9 (OIT), 10 (oven aging), and 11 (UV aging) are endurance related and key to geomembrane durability. Carbon black content and carbon black dispersion represent the most important protection against UV radiation. Some master batch (the additive that contains the carbon black) manufacturers report that the highest efficiency is achieved between the 2.5 and 3% of carbon black in the final geomembrane (Juan Salfate, Ampacet). When combined with the adequate thickness, the resulting geomembrane could withstand the aggressive conditions that have been discussed.

Stress crack resistance is tested using NCTL (Appendix A). It is a key test that will stop all unfit resins but also a few good ones. Those few resins that are disqualified by way of poor test reproducibility are an acceptable sacrifice for mining applications. Stress cracking failures are not desirable and any measure to avoid them is very welcomed. This makes the possible pool of resins and recipes smaller for a manufacturer and also explains why it is a good practice to use resins specifically manufactured for the production of geomembranes. Such a conservative measure is warranted until full knowledge of the formulation and its specific long term field performance is known.

Oxidative induction time, when linked to the Aging tests (UV and Oven aging) is a very useful index that allows inference to the durability of the geomembrane. To understand better the meaning of the OIT and how it relates to the endurance of a geomembrane, the following analogy is offered: It is well known that any steel structure is subjected to oxidation. As a consequence, a layer of paint is generally placed on the structure to protect it against the elements. The quality of the protection level is judged by the paint layer thickness, how well the paint adheres to the steel and how well it endures the service conditions. In the same respect, the geomembrane needs protection against oxidation. The OIT gives an index that is analogous to the paint thickness. The UV and the oven aging test will answer how effectively it protects. There is just one more question that has not been answered; that is, how well does the antioxidant adheres to the resin matrix of the geomembrane?

To meet the OIT specification in GM13 it is easy to add an adequate amount of antioxidants until the threshold is reached. However, to make the AO package effective is a matter of research and experience. The development of a new test, which answers the adherence capability of the antioxidant, is needed. There have been cases of geomembrane meeting GRI-GM13, in contact with leach solutions at elevated temperatures, where the antioxidant package was leached to the point that it could not be detected by the OIT test. This finding suggests that the degradation mechanism at work have progressed past Stage “A” induction time as discussed by Hsuan and Koerner.

SIP Delamination (12), a very rare phenomena, is usually checked by an in-house test, and not reported for there is no standard test method currently available for this phenomenon. SL’s in-house procedure is an observational method and merely subjective. Delamination is observed uniquely in thick HDPE geomembranes and normally detected by performing tensile tests at a rate of 500 mm per minute. The cause of delamination is still an unsolved mystery; Struve and Allen suggest low molecular weight material in the master batch, Nobert suggests uneven cooling, Smith and Peggs suggest contamination, but all are theories at this time. However, it appears that the causes are not unique. Manufacturers care about this phenomenon because of the owners reaction against it when detected while running field tensile test during the installation process. To date, there has been no reported field failure related to the SIP phenomenon. In addition, SL believes that the cause of SIP is a combination of the Struve and Nobert theories. According to SL's experience we do not believe that SIP is a result of contamination. As a matter of fact the in house SL procedure involves a special pattern as shown in Figure 15, which increases the likelihood of detecting SIP, for it crosses the flow line of the resin exiting port on a blown film line, suggesting agreement with the Struve and Allen theory.

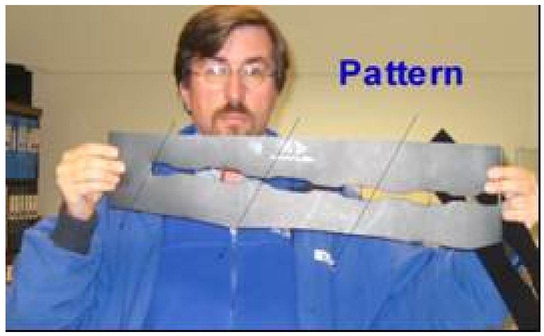

Figure 15. Specific pattern for sample extraction (SL SIP in-house test).

CONCLUSIONS

Geosynthetics are used in the design and construction of various mining facilities for process solution containment (heap leach pads, solution ponds and tailings impoundments). Due to the nature and location of mining projects, the performance envelope of geosynthetic materials is often pushed beyond the limits of typical design procedures, testing, and construction methods. Common issues addressed in mining applications include:

- Geomembrane liner and plastic pipe performance under very high loads (in excess of 3 MPa);
- Solution containment liner systems founded on compressible fills;
- Liner construction under harsh environments; and

To cope with these harsh conditions, premium materials need to be used and a good CQA is strongly recommended.

In contradiction to other applications than mining, forensic analysis is not always possible due to the hazardous substances contained and the large overburdens. Therefore it is recommended that more electric leak detection technology be used to CQA these systems prior to putting them on-line. Such systems would allow for monitoring and defects detection that years ago were unavailable.

A forensic analysis is the best answer to improve the technology and the designs. The huge heap leach projects, where the cost of the consequences of failures or just small defects are overwhelming, should lead users, manufacturers and designers to investigate the geosynthetics behavior with a consequence of developing new standard test methods, that helps to visualize the final performance of the material.

Considering the huge investments in mining facilities, the installation of monitoring stations will provide the customers with fast and accurate solutions in case of problems, and provide designers, installers and manufacturers with knowledge and experience for future projects. Other considerations that were not discussed are:

- *Interface Shear Testing*. Interface shear testing (ASTM D5321) is also required to ensure stability of the liner system under the anticipated loading conditions.
- *Monitoring of geomembrane installation*: Subgrade acceptance prior to geomembrane installation (limitation of projecting rocks and limited desiccation cracking of soil liner)
- *Monitoring of drainage layer placement*: Observation of the drainage layer includes ensuring the materials are placed according to project specifications with regard to equipment used for placement, minimum drainage layer thicknesses are maintained (function of equipment used for placement), and care taken by the contractor to limit damage to the underlying geomembrane.

All this is being done in an extremely harsh environment. Climate considerations must also enter into the selection of geomembrane liner type and design of the facility. Consideration must be given to the following:

- High elevations (greater than 3000 m);
- Heating by solar radiation, exposure to UV and large temperature variations;
- Areas with high winds with respect to facility design and construction specifications;
- Limitations to the maximum amount of exposed liner (prior to placement of ballast or overliner fill). Construction schedules are often adjusted to maximize liner deployment during periods of the day when winds are the lightest;
- Areas with high rainfall, liner deployment and installation must be scheduled based on the weather forecasts to maximize deployment during dry periods. This can be a difficult challenge in areas with annual precipitation in excess of two meters. In the design process, the facility design may include several expansion phases to minimize the footprint to ease construction. For example, the footprint of the facility may be decreased so that it matches the liner deployment rate over a dry season. It must be noted that adding phases to facility construction also adds costs that must be taken into account;
- Areas of high snowfall, liner deployment is also based on weather forecasts. Liner seaming can be completed in cold temperatures provided proper seaming temperatures can be maintained. Facility phasing may also be included in the design to ease construction;
- Areas with variable temperatures, care must be taken to minimize liner stresses due to expansion and contraction of the liner.

These considerations can be addressed in the facility design and construction. By limiting the amount of exposed liner one can avoid problems.

GRI-GM13 and GM17 have been important milestones for the industry. However there is a need to keep improving and promoting the creation of additional standards for the others geosynthetics materials. A good standard or a good specification is not the one that requests the top value for each test but the one that requests the wisest combination of values to maximize product performance on a benefit cost basis.

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