Bituminous geomembrane in mine construction

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ABSTRACT: First of all, we will give some case history of different applications all over the world for storage solid wastes: Heap Leach pad in Chile, copper mine (Codelco, Barahona mine) and in Mexico, bottom of landfill of solid wastes in Brazil, capping solid wastes: in Chilean Patagonia and in Australia with possible re-use of the geomembrane for other works and for storage of liquid wastes: tailings dams in Siberia, Kupol, in Quebec, Lake Bloom in Quebec, Timmins, tailings reservoirs: Diavik (North West Territories, Canada), Guatemala, Toromocho (Peru).
In a second step, we will present the different components of a bituminous geomembrane: mainly a polyester geotextile giving the resistance impregnated of elastomeric bitumen which gives the watertightness.
In a third step, we will give for each of the examples mentioned here above, the reasons of the consultant's choice among advantages of BGM: high puncture resistance and UV resistance may eliminate the need for cushion geotextiles, very low thermal expansion coefficient permitting welding and covering at any hour of the day, at any kind of temperature, the ability to be installed in very harsh climatic conditions with wind speeds more than 100 km/h, even under light rain. BGM does not require a specialty installer and equipment, it can be installed by the mine's own work forces or by the general contractor allowing better control of the schedule. Like this, we reduce delays and we allow a quicker use of the facility. The ability to connect to other materials such as rock, concrete, steel.

Keywords: Bituminous geomembrane, Pads, Capping, Tailings, Puncture, Wind, Installation

1 INTRODUCTION

Five thousand years ago, crude petroleum emerged from deep fissures in the ground. The heavy residue contained a high percentage of bitumen, which the ancients, especially in the Middle East, used for its waterproofing properties. Since those early times, it has been used to build and repair wells, reservoirs, canals, and baths and consolidate irrigation canal embankments. Many of these constructions are still today in good condition.

Bitumen emerged as a standard 20th century waterproofing material in civil and water engineering in the form of bituminous concrete, asphalt, and bituminous geomembrane.

Bituminous geomembranes (BGM) have been used extensively in a wide range of mining applications since they were initially developed in 1974. The applications for BGM in mining include tailings dams, water supply dams, hot brine ponds, canals, stockpile covers and capping of contaminated land.

There are different examples of applications in the mining industry in storage of:

- ✓ Solid wastes
  - o Heap Leach and storage of solid wastes after leaching in France, Chile, Turkey, Mexico,
  - o Bottom of Industrial landfill of solid wastes in Brazil,
  - o Capping solid wastes: in Chilean Patagonia and in Australia with possible re-use of the geomembrane for other works, storage of low radioactive wastes in France.
- ✓ Liquid wastes

o Tailings dams: in Peru, in Siberia, Kupol, in Quebec, Lake Bloom, in Ontario: Timmins
o Tailings reservoirs, in the North of Australia, installation in summer by temperature near 50°C, storage at high temperature for shale gas site, Guatemala, Toromocho (Peru) at an altitude of 4,800 m in a very windy region.

2 HEAP LEACH AND STORAGE SOLID WASTES IN MINE CONSTRUCTION

In France

BGM have been used in heap leach pads for extracting uranium. The HLP was lined with BGM as shown here-under. BGM was selected for its durability and high puncture resistance.

Figure 1. Uranium leaching in Limoges, France

In Peru

In the Antamina mine (Copper), a BGM was used to line a copper heap leach pad at an altitude of more than 4,000 m as shown here-above because:

- There were extreme weather (see § 4: Summary for values weight, cold bending by cold temperature) conditions on this mine site at this altitude, with lot of wind, sudden changes of weather and very cold temperatures.
- The superior puncture resistance (see § 4: Summary for values) of the BGM permitted the use of a single layer of BGM without protection geotextiles, and this enabled a faster installation schedule in these extreme conditions as only one geomembrane needed to be installed rather than a thinner polymeric geomembrane and two protection geotextiles.

Figure 2. Antamina, Peru

In Chile

A storage of rocks named Barahona Acid Spoils Dump in an underground copper mine in Rancagua, Chile. Sinclair, Knight & Merz (SKM) in Santiago, Chile designed the project.

The project is destined to permanently store the acid waste materials resulting from an underground mine.

The project was initially designed with four layers of LDPE. The client had the design changed to use of BGM 5.6 mm and a unit mass of 6.4 kg/m^2. The key arguments to use BGM were the reduced requirements for surface preparation to deploy the geomembrane (thus reducing time to install and therefore installation costs), the larger tensile and shear strength, its higher resistance to puncturing (providing more resistance during the construction of the dump and subsequent deployment of the waste layers), the higher surface mass and larger dimensional stability.

The spoil dump will be built in ten distinct stages until it reaches the final elevation at 1605 meters above sea level.

Figure 3. Large boulders removed

Figure 4. A 5.6 mm thick BGM deployed

Figure 5. Leachate collector

The surface preparation was limited to scarification and vegetation clearing, removal of large boulders and removal of rocks larger than 60 mm. The BGM was selected for the leachate collector channel because of its UV resistance and its low Manning's coefficient of a BGM giving another advantage for using a BGM for storage heavy material, as the transversal slope of 2% is enough for assuming a good flow of leachate and this entails less excavation.

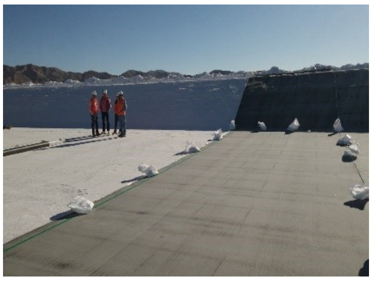
In Atacama: Lithium pads

The process to obtain lithium from brine is the following:

The salt-rich waters must first be pumped to the surface into a series of evaporation ponds where solar evaporation occurs over few months.

Different minerals are harvested from early ponds, while later ponds have increasingly high concentrations of lithium. When the lithium chloride in the evaporation ponds reaches an optimum concentration, the solution is taken to a treatment plant where unwanted minerals (like boron or magnesium) are removed.

Here is a Lithium pad in Atacama (Chile), please remark BGM perfectly without any wrinkles despite high temperature



In Turkey

A BGM was also used for the gold leaching facilities at Efemcukuru gold mine in Turkey. Here-under photos show deployment of the geomembrane with the anchor trench on the left-hand side. A BGM was selected because it could be installed by the mine's own workforce (after training by a BGM manufacturer monitor), the high puncture resistance, and the high interface frictional resistance as the area is characterized by a high seismicity and stability of slope under seismic load.

A cushion geotextile was not needed. The larger mass per square meter compared to other geomembrane was also a deciding criterion since the areas are characterized by high winds.

Due to the strong slope of the ground, anchoring trenches were realized for every panels of geomembrane, to avoid any sliding. This was possible due to the flexibility of BGM (see § 4: Summary for values Elasticity modulus)

In Mexico

The Dolores mine is situated in the municipality of Madera, in the Sierra Madre, state of Chihuahua in Mexico. It is an opencast mine for the extraction of the gold and of silver.

For the construction of this pad, the consultant chose a 4,8 mm BGM with a unit mass of 5,80 Kg/m2 to be placed as the first layer at the bottom. A 0,6-meter drainage and leak detention layer plus a LLDPE layer were installed on top of the BGM as shown in Figure 6, 7, 8.

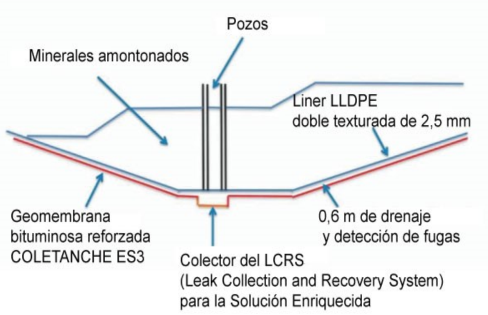


Figure 6. Cross section of the HLP


Figure 7. BGM deployment


Figure 8. Work completed

Due to the strong slope of the ground, anchoring trenches were realized for every panels of geomembrane, to avoid any sliding.

2.1 *Bottom of landfill of solid wastes in Brazil*

A BGM was used for basal lining of a solid waste storage facility at a niobium (rare earth) mine in Brazil. The BGM was the perfect solution, as due to its puncture resistance it could be used in direct contact with the low permeability (10^{-5} m/sec) laterite subgrade.

The overall cost of the work was cheaper than the initially proposed solution with a polymeric geomembrane, and the BGM also presented a safer environmental solution as the BGM stays in intimate contact with the low permeability subgrade despite the high temperature fluctuations.

2.2 *Capping solid wastes*

2.2.1 *In Chilean Patagonia: capping of wastes of gold mines for definitive closure*

The BGM was selected for this mining in Chile due to its high puncture strength and its ability to handle extreme weather conditions. Work was done in one year and the foreseen schedule was 2 years with LLDPE.

Figure 9 &10. BGM for mine waste in Chile

2.2.2 *Capping of heavy metal concentrate stockpiles in Australia with a heavy weight reusable BGM Liner*

BGM can sustain wind speeds 3 to 4 times higher than lighter polymeric geomembrane. Consequently, on a mine site, a BGM could be installed under stronger wind conditions than other types of geomembranes.

On this project, the challenge was to cap the stockpile of this mineral stored (titanium) during low prices without bonding the edges of the BGM, so the pile could be opened and BGM could be re-rolled and re-used.

What you can see here-under was a test of 3 years, the client taught that it was a good solution despite the cost and the total pile will be covered in 2018.


Figure 10 & 11. BGM as stockpile covers

2.2.3 *Storage of low radioactive wastes in France*

Low level short half-life nuclear waste is stored at the Manche repository in stacked canisters covered with a multi-layer capping to prevent ingress of rainwater. The cap includes a thick

BGM 5,6 mm thick, chosen for its ability to remain watertight for 300 years, following studies during 7 years in France (Andra now Areva) and in USA (Laboratories of Nuclear Safety Agency based in Washington State) that studies were done and conclude at the exceptional durability of BGM 300 years with a biodegradation of maximum 1,5 mm on both side. The other conclusion of these studies was also the best behavior of bitumen in presence of radius α giving sense for its use in mine of uranium.



2.3 *Storage of liquid wastes*

2.3.1 *For tailings dams*

2.3.1.1 *In Siberia, Kupol, Russia*

BGM was selected due to ability to handle extreme weather conditions (Work even in February by -45°C) and like this able to sustain tight schedule.



2.3.1.2 *In Quebec, Lake Bloom, Canada*

Bloom Lake's mine is located approximately 9 miles southwest of Fermont, Quebec, being part of the southwest corner of the Trough Labrador iron mine.

Operations consist of an open pit mine comprising of a truck and shovel transportation system. A concentrator that utilizes single-stage crushing, an autogenously grinding mill and gravity separator is used to produce an iron concentrate. From the site, concentrate is transported by rail to a ship loading port in Pointe Noire, Quebec.



Figures 12, 13 & 14. Lake Bloom, Qc, Canada

BGM was selected for this project, thanks to: time and cost savings due to the elimination of the need of geotextile and structural fill, easy to install and to repair, excellent friction angle for slope installation (34°), excellent weathering resistance even when exposed, long life expectancy, possible installation in extreme weather conditions (rainfall, wind, cold temperature down -40°C, due to its high resistance to puncture and tearing, the earthmoving contractor could use a wider range of materials for the liner bedding and cover zones.

2.3.1.3 *In Ontario, Timmins, Canada*

BGM 4.8 mm was selected due to its puncture resistance as BGM was installed against a first rockfill dam and blocked in the middle of material pushed against BGM. Like this, BGM was in the middle of a new dam. The watertightness of the new dam was a lot improved due to the presence of BGM with a coefficient of imperviousness of 10^{-14} m/sec Darcy law. Slope was inverted in what is usually made for dams.


2.3.1.4 *In warm country: Dugald river zinc mine, Queensland, Australia*

BGM 4,8 mm was chosen with 2 faces with the same friction angle of 34°. This choice of a BGM could provide an ideal technical and commercial solution for this challenging mining application due to its very steep (1V:1.75H) tailings dam face.

The mine was able to save hundreds of thousands of dollars in rockfill by having this steep face.

BGM (High Friction Angle,) provided the following advantages for this project:

a) Excellent friction under the liner to maximize slope stability

b) Excellent puncture resistance on the gravel subgrade

c) An extremely low co-efficient of thermal expansion, which meant that BGM would not expand and contract like a plastic liner with the associated problems from thermally induced wrinkles on this very hot site in central Queensland


2.3.2 *Tailings Reservoir*

2.3.2.1 *In North West Territories (Canada), tailings reservoirs: Diavik*

BGM was selected due to its puncture resistance and ability to handle extreme weather conditions. Installation and welding were possible 10 months per year from February till the end of the year. We are working on this site for 10 years and we continue to work. Client satisfied certainly.

2.3.2.2 *In Guatemala*

The Escobal mine, located about 70 km southeast of Guatemala City, is the third largest silver mine in the world. The mine is at an altitude of about 1,300 m. It is an underground mine located in a tropical climate, demanding a strict surface runoff control. BGM stays exposed. BGM was selected for wind, earthquake and UV resistance



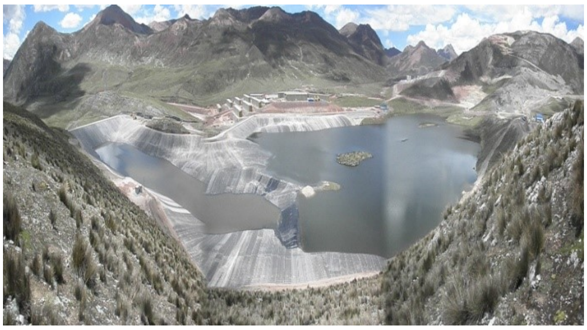
Figure 15. HDPE with wrinkles

Figure 16 & 17. BGM without any wrinkle

On the same mine, at the same hour.

2.3.2.3 *Toromocho (Peru). 4,800 m of altitude*

BGM was selected to contain liquid mining waste was selected due to its puncture resistance and ability to handle extreme weather conditions (at this altitude: high speed wind impossible to sustain delay with light geomembrane, quick change of weather. BGM can be welded under humid atmosphere). BGM stays exposed despite the altitude.

2.3.2.4 *In Australia: Helensburgh Coal Mine, New South Wales, Australia.*

BGM 4,8 mm thick was used on this environmentally sensitive project to give a high level of protection against damage. BGM was used to create a stilling basin for coal contaminated stormwater from the mine. The puncture resistance of BGM played an important role on this project. Also, the ability to place a concrete slab directly on BGM (to enable regular pond cleaning) was a distinct advantage.

3 PRESENTATION OF THE DIFFERENT CONPONENTS OF BGM

A BGM is a geomembrane manufactured by impregnating a long fiber polyester geotextile with a bitumen compound. The geotextile provides the mechanical resistance and the high puncture resistance. The bitumen provides the waterproofing properties of the geomembrane and, also, ensures the longevity of the composite by totally impregnating the geotextile. The BGM composite also includes other components as illustrated here under

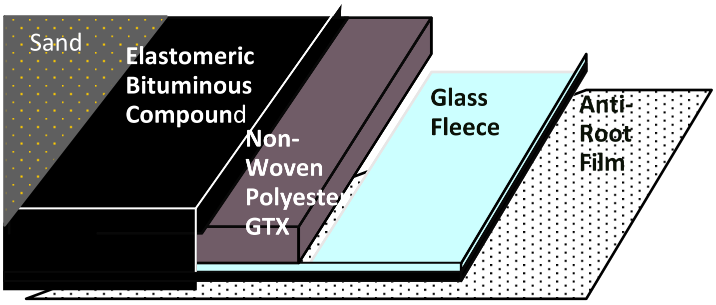


Figure 18. Schematic cross section of BGM

The non-woven polyester reinforcement from 250 gr/m^2 up to 400 g/m^2 (or more if necessary) and overall thickness of the composites are from 3,5 mm up to 5.6 mm.
The BGM is by far the thickest and heaviest geomembrane on the market.

4 SUMMARY

of the different advantages proven by tests results which did the difference for choosing BGM by consultants and owners. These test results were done in different laboratories mainly in Canada (Sageos in Québec) for ASTM tests, and in France at the lab IRSTEA of the French ministry of Agriculture for AFNOR and CEN tests but also in Russia following GOST standards.

Characteristics	Standard	Unit	BGM	HDPE	LLDPE
1 - Physical characteristics					
1.1 Thickness		mils	158	60	60
1.2 Density	ASTM D1505/ D792	lb/ft³	79	59	57
1.3 Width		ft	17	23	23
2 - Mechanical characteristic					
2.1 Tensile-Tear resistance	ASTM D4073 / D1004 / D5884	lb	203	42	33
2.2 Puncture Resistance					
Static Puncture	ASTM D4833	lb	135	108	102
2.3 Hydrostatic Puncture	ASTMD 5147	kPa	501		
3 - Thermal Properties					
Dimensional Stability	ASTM D1204	%	< 0,1	2	1
4 - Friction Angle					
Rolled sand	ASTM D5321	°	32	18	22
5 - Gas transmission					
CO2	ASTM D1434	m³/m²/day	<7.8.10^{-7}		
6 - Flexibility					
Elasticity Modulus					
at - 30°C		MPa	20		
at + 20°C		MPa	1	484	220
Cold bending at cold t°	ASTM D746	°C	-30		

This chart shows that

- its ability to be installed in very harsh climatic conditions due to its unit mass, even with wind speeds more than 70 km/h, even under light rain and with temperature of artic conditions,
- does not know the phenomenon of stress cracking,
- the high static puncture resistance due to the presence of a strong geotextile inside the geomembrane protected over the time by bitumen:
- means the ability to run directly on the geomembrane during the work (see Fig 19a). This ease the work for other contractors during installation and maintenance,

Fig. 19a Traffic directly on BGM

- allows the use of coarse grain material directly on the geomembrane, namely for the cover material of the heap leach pad as shown on Figure 19b or for capping, eliminating the need for screening of material (if otherwise required) or placement of a cushion geotextile, thereby saving time and money,

Figure 19b: Coarse grain material directly on BGM.

- very low thermal expansion coefficient permitting welding and covering at any hour of the day and at any kind of temperature,

Furthermore, we would mention:

- its ability to receive asphalt concrete at a normal temperature of spreading of 140C° to do cleanable tailings reservoir (see Fig. 20 § 21)**:**

Figure 20 & 21. Asphalt concrete spread directly above BGM for cleanable tailings reservoir

- its UV resistance. BGM can stay exposed
- Due to the assistance provides by the manufacturer and the simple equipment required (torch), it can be installed by the mine's own work forces or by the general contractor or by the earthmoving contractor allowing better control of the schedule and a very low price for installation and maintenance. Like this, we reduce delays and we allow a quicker use of the facility.

5 CONCLUSION

Before deciding the choice between a polymeric geomembrane and a BGM, the consultant must compare cost of global solution including delay in function of weather conditions able to meet on a site, ease to do the works for all the different contractors and so, the ease to meet even tough schedule.
The consultant must try to anticipate the cost for his client of a delay of 1 day of production of gold, silver, zinc, lithium etc;….

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