# Bituminous geomembranes (BGM) for heap leach pads and dumps for solid wastes in mine construction



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# ABSTRACT

This paper will describe the structure of a bituminous geomembrane (BGM) and discuss laboratory testing that attest to its performance, and project case studies in mine construction. A BGM is a geomembrane manufactured by impregnating a polyester geotextile and a fiberglass layer with an elastomeric bitumen compound. The geotextile provides the mechanical resistance and a high puncture resistance, thus permitting the dump of ore directly on the geomembrane and permitting the traffic of equipment (trucks, loaders, etc.) directly on the BGM during construction, maturation of wastes or maintenance. The elastomeric bitumen provides the waterproofing properties of the geomembrane and ensures its longevity by protecting the geotextile fibers over the long run. The installation of this geomembrane can be allowed in low temperatures down to -40°C, permitting works for 10 months per year in cold regions or at very high altitudes of 4,600 m. The high friction angle of bitumen of 34 degrees for example provides a strong adherence in steep slopes, allowing a high volume of material storage directly on the geomembrane.

Test results of chemical resistance done in Europe, Canada and in Kazakhstan indicates the ability of using BGM in heap leach pad construction. Several examples of applications in mining where BGM was selected over of a more traditional type of geomembrane: a heap leach pad and storage dump for solid wastes at a uranium mine in France in 1976, the Antamina copper mine in Peru, the Barahona acid spoil reservoir at Codelco's Teniente mine in Chile, Dolores silver mine in Mexico, and other examples in eastern Europe. The advantageous characteristics of BGM reflects on economic benefits, as well as installation in certain weather conditions of fierce winds, light rain, and very cold temperatures.

# 1 INTRODUCTION

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, canals, stockpile covers and capping of contaminated land (biogas barrier), heap leach pads, and solid waste dumps.

# 2 DESCRIPTION OF THE BGM PRODUCT

A BGM is a geomembrane manufactured by impregnating a non-woven polyester geotextile and a fiberglass layer with an elastomeric bitumen compound. The geotextile provides the mechanical resistance and the high puncture resistance. The bitumen provides the waterproofing properties of the geomembrane and ensures the longevity of the geomembrane by totally impregnating the geotextile. The BGM also includes other components as illustrated in Figure 1. The non-woven polyester reinforcement of 400 g/m<sup>2</sup> provides an overall thickness of the geomembrane of 5.6 mm. BGM's are a thick and heavy geomembrane that have advantageous characteristics suited for mining applications.



Figure 1. Cross section of BGM's composite structure

# 2.1 Tensile Properties

The tensile properties of a BGM are derived primarily from the geotextile at the core of the product. When stressed, a BGM will show an approximate linear response typical of a non-woven geotextile, up to failure at a strain of approximately 70% to 100%. Unlike polymeric geomembranes that have a yield point around 12%, BGM has no yield point. Engineers (ex. JP, Giroud) conventionally take 35% for BGM from the tensile curve. Furthermore, the bitumen component can accommodate very large strains because of its viscoelastic property (Cerema Laboratory, French Ministry of Transport).

#### 2.2 Ageing

The effect of ageing on the tensile strength of BGM has been investigated in various laboratories. The testing of BGM has shown no significant reduction in tensile properties with time. To determine the long-term ageing and effectiveness of existing potential covering membranes, ANDRA (French National Agency for managing radioactive waste) determined that the BGM would have a resistance to bio-degradation for over 300 years (Convert, Coquille and Herment, 1993). Some other tests done by Safety Nuclear Agency in USA, also confirm these results. This can be backed up by how bitumen has been used since antiquity to waterproof structures (Krishnan and Rajagopal, 2003).

## 2.3 Chemical resistance

As mentioned, BGM is made of a geotextile impregnated by a mastic with a bitumen component called "Bitumen Industrial", which is not the usual bitumen used for road construction (Morgan, P.).

Before BGM was used in mine construction, several tests were done primarily by Shell, one of the two inventors of this bituminous geomembrane in the 1980's, and reported their results in the Shell Bitumen Industrial Handbook (Morgan, P.). In their laboratory of Amsterdam, they studied the influence of different chemical products under different temperatures ranging from 0°C to +75°C of the solution and concentrations ranging from 0 to 100%. For example, at a 10% concentration of nitric acid, there is no attack at room temperature (Tessier, D.). We could summarize this study stating for each solution of pH between 4 to 11 at ambient temperature, there are no chemical concerns. For more acidic or basic solutions, a precise examination is necessary with the exact chemical analysis of the solution in contact with BGM and its temperature of use.

For some projects, clients prefer to have specific laboratory testing with the actual concentrations and temperatures of the project. This was the case for heap leach pads in Chile and Peru, and for a project of extraction of copper in the Canadian Yukon Territory, where they concluded positive testing for 20% of sulfuric acid and 100ppm of kerosene for a period of three years (Esford, F.). In Kazakhstan (Kushakova, L.B) and in Russia (GOST), they required tests of chemical resistance before approving the use of the BGM product in their territory's heap leach applications for the mine sector.

#### 2.4 Puncture resistance

Due to its thickness and the presence of an impregnated non-woven geotextile at the core, BGM exhibits a strong resistance to puncture allowing:

 The use of larger aggregates in the subgrade (up to 75mm) and rocks in the cover layer (up to 400mm) without the need for a cushion geotextile. When the BGM is penetrated or indented by a protrusion, the viscoelastic nature of the bitumen comes into play and the bitumen takes the shape of the protrusion and coats it as shown in Figure 2a.



Figure 2a. BGM adapts to irregularities

• Light to medium construction equipment (up to 8 tons with rubber tires) to drive directly on the BGM as shown in Figure 2b.





• The use of coarse grain material directly under and on the geomembrane, as shown in Figure 3, eliminating the need for screening of materials (if otherwise required) or placement of a cushion geotextile layer, thereby saving time and money for the owner.



Figure 3. Coarse grain material directly on BGM. A cover layer of 20-30 cm thick serves to receive the ore to be leached.

#### 2.5 Extreme temperature application

Bituminous geomembranes have a very low coefficient of thermal expansion compared to that of polymeric geomembranes  $(2.2 \times 10^{-3} \text{ mm/m/°C} \text{ versus } 1.0-2.5 \times 10^{-1} \text{ mm/m/°C})$ . This gives the BGM a distinct advantage on mine sites that are exposed to extremely hot or cold environmental conditions, or huge temperature variations during the day. BGM does not expand and contract under these temperature variations like a polymeric geomembrane, which allows for the mine to spread materials all day on heap leach pads or dump areas on a surface without any wrinkles.

Figure 4a shows a BGM being laid in a silver mine in Guatemala during a sunny day with an ambient temperature of 39°C. The BGM lays flat on the foundation soil with no wrinkles. Figure 4b shows a polymeric geomembrane under the same temperature, where many wrinkles are revealed. In the case of the polymeric geomembrane, it is necessary to wait for the temperature to reduce before installing a geocomposite on top or to cover it with ores or solid wastes. This time delay is necessary to reduce the number of wrinkles.



Figure 4a: BGM presenting no wrinkling



Figure 4b. Polymeric geomembrane wrinkling

## 2.6 Wind uplift resistance

The BGM typically used for heap leach pads has a minimum mass per unit area of  $4850 \text{ g/m}^2$  up to  $5800 \text{ g/m}^2$ . This mass per square metre is more than three times that of a 2 mm thick polymeric geomembrane or more than four times that of the common 1.5 mm polymeric geomembrane. With its mass, BGM can sustain wind speeds 3 to 4 times higher than the mentioned lighter polymeric geomembranes and on a mine site, BGM can be installed under strong wind conditions and can be left exposed.

## 3 BGM APPLICATIONS IN THE MINING INDUSTRY: STORAGE OF SOLID MINING WASTES

- 3.1 Heap leach pads (HLP) are typically lined with a composite liner system that consists of the following components, from top to bottom:
  - A drainage layer (the over liner), typically consisting of gravel or free draining materials,
  - A geomembrane (the primary liner), and
  - A barrier layer (the secondary liner) which can be a compacted clay layer (or low permeability soil) typically 30 cm thick, or a geosynthetic clay liner (GCL) or another geomembrane (double liner system).

The ore is then piled up on top of the over liner and the leaching solution is applied on top of the ore to leach out the precious metals.

The main role of the composite liner system is to eliminate leakage of the pregnant leach solution into the subsoil and to allow a full recovery. This is important for at least two reasons:

- It holds the dissolved metals (the pregnant leach solution) that are the source of revenue for the mining operations;
- It contains chemicals that may be harmful to groundwater.

Loss of revenue from leakage of the pregnant solution from heap leach pads can be considerable (Peck, 2014). In designing the composite liner system, an engineer has many choices for the selection of the geomembrane and the barrier layer. BGM has proven to be a good solution to the challenges faced by many mine owners and operators due to its strong puncture resistance, easy deployment and climate resistance.

In France, BGM has been used in heap leach pads for different metals. An application in Limoges, France for uranium leaching is shown in Figure 5. BGM was selected for its durability and high puncture resistance to line the HLP.



Figure 5: Uranium leaching in Limoges, France

In Peru, the Antamina mine (Figure 6a & b) used BGM to line a copper heap leach pad at an altitude over 4000 m above sea level because:

 The superior puncture resistance of the BGM permitted the use of a single BGM layer without protection geotextiles. This enabled a faster installation schedule in these extreme conditions as only one geomembrane is installed rather than a combination of a thinner polymeric geomembrane with two protection geotextiles.



Figures 6a. Antamina copper mine, Peru



Figures 6b. Antamina copper mine, Peru

In Central Asia- Kazakhstan:

 Tokhtar gold mine: BGM was used to line a heap leach pad due to its ability to sustain delays despite extreme weather conditions and due to its superior puncture resistance permitting the use of a single layer of BGM without the need for protection geotextiles. Efficient installation was done by local workers trained by the manufacturer (Figure 7).



Figure 7. Tokhtar mine KZ, after 1 day of installation

 Kogadyr gold mine: in Zhambyl region of the Republic of Kazakhstan, BGM was selected for similar reasons for efficient installation by local workers trained by the manufacturer (Figure 8).



Figure 8. Kogadyr gold mine in Kazakhstan

3.2 Drumps area of solid wastes

The Barahona Acid Spoils Dump belongs to Codelco's Teniente underground copper mine in Rancagua, Chile. The project was designed by Sinclair, Knight & Merz (SKM) in Santiago, Chile. The purpose is to permanently store the acid waste materials resulting from the excavation of the access tunnels for the Nuevo Navel Mina at the Teniente underground mine. It is located 44 km east of the town of Rancagua.

The project was initially designed with four layers of LLDPE. Codelco had the design changed to use of a BGM of 5.6 mm with a unit mass of 6.4 kg/m<sup>2</sup>. The key arguments to use BGM were for the reduced requirements for surface preparation before deploying the geomembrane (thus reducing time to install and installation costs), the high tensile and shear strength (providing more resistance during the construction of the dump and subsequent deployment of the waste layers), the high surface mass and dimensional stability (that allow installation of the geomembrane under any weather conditions without wrinkling), and its strong resistance to puncture.

The final design of the watertight solution included: a) a 20 cm layer of crushed material that serves as the support under the BGM; b) a layer of BGM (5.6 mm thick); and c) a 20 cm layer of crushed material on top of the BGM. This latter layer allows the trafficability of the highway trucks transporting the waste from the tunnel excavation face and the bulldozers used to spread the material.

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



Figure 9. A 5.6 mm thick BGM deployed at Barahona acid spoil dump

The subgrade preparation was limited to vegetation clearing, removal of large boulders and removal of rocks larger than two inches.

The BGM was selected for the leachate collector channel because of its UV resistance, as shown in Figure 10. The low Manning coefficient of BGM where a transversal slope is of 2% is enough to assume a good flow of leachate, which entails less excavation.



Figure 10: Leachate collector at Barahona acid spoil dump staying exposed

In Turkey, A BGM was used for the gold leaching facilities at Efemcukuru gold mine. The mine is owned by Eldorado Gold Corporation based in Vancouver. Figure 11a shows 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 the BGM manufacturer personnel), because of the high puncture resistance and the high interface frictional resistance as the area is characterised by a high seismicity, requiring stability of slope under seismic effects.



Figure 11a. Efemcukuru mine in Turkey



Figure 11b. Efemcukuru mine in Turkey

In Mexico, the Dolores mine belongs to the company Pan American Silver Corp and it is situated in the municipality of Madera, in the Sierra Madre, state of Chihuahua in Mexico. It is an open-pit mine for the extraction of the gold and silver.

For the construction of this pad, Golder Associates Engineering chose a 4.8 mm BGM with a unit mass of 5.8 kg/m2 to be placed as the first layer at the bottom. A 0.6meter drainage leak detection layer and an LLDPE geomembrane liner were installed on top of the BGM (Figure 12).



Figure 12. Cross section of the pad at the Dolores mine in Mexico

Figure 13 shows the BGM deployed at the Dolores mine site. Due to the steep slope of the ground, anchoring trenches were done for every panel of geomembrane, to avoid sliding. This was possible due to the flexibility of BGM.



Figure 13. Steep slope at the dump area of Dolores mine in Mexico

# 4 CONCLUSION

The use of BGM in mining applications has increased over the past few years due to both technical and overall financial advantages. Considering the ease of installation by local workers who can be trained by the manufacturer personnel, they could also easily take care of repairs or do a project extension. As described in the paper, technical advantages include:

- The longevity of BGM compatible with the life of a mine;
- A strong puncture resistance, which allows the use of local material or mine waste to be used directly on top as a cover and under as subgrade for the BGM.
- BGM can be installed in very harsh climatic conditions where the wind speed can exceed 70 km/h and temperatures could be well below zero degrees Celsius. A complete absence of wrinkles permits to place material directly on BGM whatever is the time of day or year, which allows the heap

leach pad to be used sooner and generate revenue earlier.

- The possibility to run light to medium weight construction vehicles (up to 8 tons with rubber tires) directly on the BGM geomembrane during construction or maintenance.
- Large sized aggregates can be placed directly on top of the BGM, eliminating the need for screening and segregation.
- The reduced risk of leakage through the liner, due to its puncture resistance, minimizes the risk of contamination of the groundwater.

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