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BGM testing program for use in heap leach pads

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ABSTRACT: Normal practice in Latin America for the waterproofing of heap leach pads involve the use of polymeric membranes (either HDPE or LLDPE) normally coupled with a medium-weight geotextile to protect the polymeric membrane liner from puncturing. Use of a bituminous geomembrane (BGM) for this application is conceptually appealing to the mining industry since it provides the waterproofing with a single geosynthetic as well as the elimination of an additional interface (polymeric membrane against geotextile) that may have an effect in the static and dynamic stability of the heap leach pile. A BGM manufacturer teamed with a large copper mine in Chile to test the puncture resistance of the BGM sandwiched between the overliner and the subgrade as well as the interface friction angles between the overliner and the BGM. This paper describes the test program, the results obtained and their significance for the heap leach pad.

1 INTRODUCTION

1.1 *Description of the project*

The project for which the use of a BGM was considered belongs to a major copper mine in Northern Chile. It consisted of a large heap leach pile with a design height of 100 m for the leaching of crushed ore with a density of 1.8 tons/m^3. The area of the pad to be waterproofed for the new heap leach was around 600,000 m^2 in total.

Based on the above conditions the actual puncture stress imposed by the heap pile on the waterproofing barrier of the pad is around 1,800 kPa and the mine owner defined a desired safety factor of 3.0 against puncturing. Overall, the liner would have to be tested at a maximum vertical puncture load of 5,400 kPa.

1.2 *Structure of a BGM*

The bituminous geomembrane is a multilayered product as illustrated in Figure 1 below.

The components of this bituminous geomembrane are:

- a nonwoven polyester geotextile, ranging from 200 to 400 g/m^2, that provides mechanical performance, especially the tensile and puncture strength,
- a glass fleece reinforcement that provides thermal stability during manufacturing,
- a blend of SBS modified bitumen and fillers. This blend impregnates the geotextile and the glass fleece, provides the watertightness, and ensures the longevity of the product,

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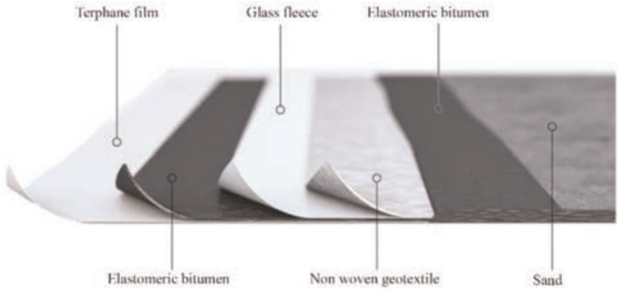


Figure 1. Cross section of bituminous geomembrane.

- a terphane film bonded to the underside, to prevent penetration of the membrane by plant roots,
- a coating of fine sand on the upper surface to provide a greater traction on slopes, and to provide increased protection against the degrading effects of UV radiation.

2 PROPOSED TEST PROGRAM

The objective of the test program was to evaluate the puncture resistance of two different bituminous geomembranes – a 4.8 mm thick BGM containing a non-woven 300 g/m^2 geotextile (internally denominated "ES3") and a 5.6 mm thick BGM containing a non-woven 400 g/m^2 geotextile (internally denominated "ES4") – under the loads imposed by the heap leach with the desired safety factor and to measure the interface friction angles at the normal load imposed by the heap to use these figures for the subsequent stability analyses of the heap.

The project requirements indicated the need to do large-scale puncturing tests at a normal load as high as 5,400 kPa and interface friction tests with a normal load around 1,800 kPa. After a careful search of existing laboratories in the Americas the factory selected the SAGEOS laboratory in St-Hyacinthe (QC, Canada) for the puncturing tests. However, the maximum load capacity was 5,000 kPa which already represents a high safety factor of 2.8. TRI Environmental laboratory in Austin (TX, USA) was chosen for the interface friction testing.

Although the main interest was to evaluate the behavior of the BGM between the subgrade and the overliner material normally used at the mine, the test program also included a series of tests with the BGM between the subgrade and the mineral to be leached with a view to eventually eliminate the overliner in the typical design and generate cost savings.

2.1 *Sampling and USCS classification of granular materials*

SGS Chile was retained to collect at the mine site the samples of the subgrade, the overliner and the mineral in the quantities required by the testing program, pack the materials in moisture-proof recipients holding 25 kg each, label and ship the materials via airfreight to each laboratory (about 300 kg for the puncture tests and 140 kg for the direct shear tests).

SGS was also tasked to do the sieve analysis of the granular materials involved. The Table 1 below contains the size consist of the different materials. Table 1 presents the size consist information of the materials in a graphical form.

Table 1. Size consists of materials (% passing).

ASTM Sieve	Subgrade	Overliner	Mineral
2 ½·”		100	
2”		99	
1 ½”	100	83	100
1”	97	56	93
¾”	94	38	84
3/8”	84	9	72
No. 4	69	1	58
No. 10	55		48
No. 40	28		29
No. 200	14		18

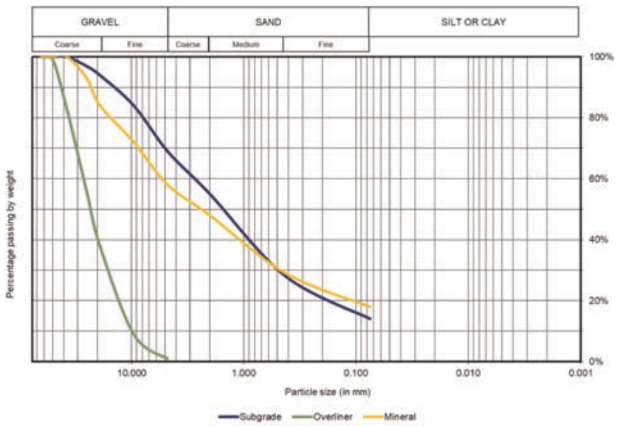


Figure 2. Size consists of granular materials.

2.2 *Large scale puncturing tests*

The large-scale puncture tests were done following a modified version of ASTM D5514, procedure B. The pressure applied to the geomembrane is exerted via a hydraulic cylinder and a small hydrostatic piezometer is used as a tool to determine whether there are leaks through the liner. Figure 3 below shows a schematic of the puncture testing device.

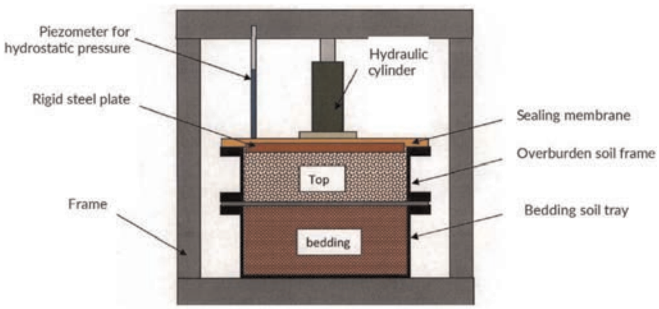


Figure 3. Schematic of puncture testing device.

Under this procedure the pressure is applied by steps in 138 kPa increments (20 psi), the normal load is held constant for 10 minutes to observe if there is a drop in the level of the piezometer. The process continues following these steps until a drop in the piezometer is observed or the capacity of the testing device (5,000 kPa) is achieved. If the latter takes place, the load is maintained for one hour.

The operational condition of a geomembrane in a heap leach pad corresponds to a "mechanical stress" condition – as described by Blond and Breul (2014) in which the geomembrane is sandwiched between a drainage layer and the support material. Each of the designated geomembranes was tested between the overliner and the subgrade and between the mineral and the subgrade. Three replications were done for each test to obtain average values.

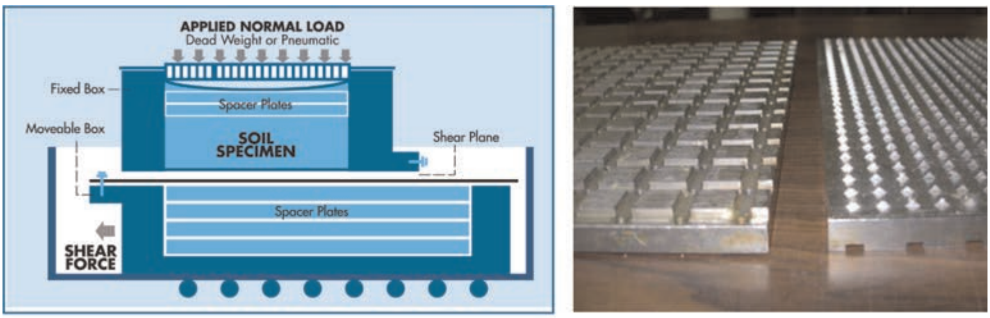
In most tests the BGM reached the capacity of the test device without puncturing, which indicates that the puncture resistance under the test conditions exceeds 5,000 kPa although the ultimate puncture resistance could not be determined. The only exception was the test of the "ES3" (thinnest product) against the overliner material, in which the membrane showed leaks when the load reached 5,000 kPa. However, in all three replications of this test, the membrane did not show any leaks in the stage immediately before the maximum capacity of the test device. The results of the puncture tests are summarized in the Table 2 below.

Table 2. Puncture test results.

Test #	Description	Puncture Resistance	Punctures Observed
1	Overliner / ES4 / Subgrade	$>$ 5.000 kPa	None
2	Mineral / ES4 / Subgrade	$>$ 5.000 kPa	None
3	Overliner / ES3 / Subgrade	$\approx$ 4.860 kPa	5,12,11
4	Mineral / ES3 / Subgrade	$>$ 5.000 kPa	None

2.3 *Direct shear tests*

The direct shear tests were done following the ASTM D5321 standard at normal loads of 500, 1,000 and 2,100 kPa. The membrane was placed inside the shear box with a pyramid-toothed grip plate underneath and the material to be tested above. Figure 4 below shows a schematic of the direct shear box and a photo of the grip plate used.



(a) (b)

Figure 4 a. Schematic of direct shear box. b. Pyramid-toothed grip plate.

For these tests, the sanded side of the geomembrane was placed against the granular material and the terphane film against the grip plate underneath. The granular materials were tamped in place and the tests were run under wet conditions (deemed to be more unfavorable) at a shear rate of 1.0 mm per minute.

The friction angle between granular materials and the sanded side of the BGM have been measured at the INSA laboratory in Lyon (INSA, 2012) using the sliding table method based on the French standard NF P 84-522. These tests showed the angle friction with gravels to be between 38° and 44°.

Direct shear tests done for the Headworks Reservoir of the Los Angeles Department of Water and Power in the United States (Lew *et al.*, 2013), using ASTM D5321 with a modified speed, showed that the interface friction angle with normal loads up to 250 kPa was around 36° for non-cohesive materials.

Direct shear tests done on railway ballast have shown that the secant friction angles decrease with an increase in the normal stress (Estaire and Santana, 2018). We have not had previous experience with direct shear tests for the BGM at the normal loads for which this test program was designed.

However, based on the above experiences, we were expecting that the friction angle at the higher normal loads would remain around 30°.

At a normal load of 500 kPa the secant friction angle varied between 27° and 30° (depending on the geomembrane and the material on top). However, when the normal load increased to 1,000 kPa, the secant friction angle was reduced to values between 20° and 24° and when the normal load increased to 2.100 kPa, the secant friction angle was further reduced to values between 11° and 14°. It was also noticed that, for the same normal load, the secant friction angles for the thicker, 5.6-mm "ES4" membrane were smaller than those for the thinner 4.8-mm "ES3" membrane. The Table 3 below summarizes the secant friction angles obtained.

Table 3. Secant friction angles.

Test #.	Description	Normal Load, kPa		
		500	1,000	2,100
1	Mineral vs ES3 (Sanded side)	30°	24°	14°
2	Overliner vs ES3 (Sanded side)	29°	21°	14°
3	Mineral vs ES4 (Sanded side)	27°	21°	12°
4	Overliner vs ES4 (Sanded side)	27°	20°	11°

The friction angles derived from the Mohr-Coulomb's linear envelopes obtained from the above tests ranged from 4.3° to 7.5° for the peak stress and from 1.8° to 4.9° for the large displacement measurements. Once again, the friction angles for the thicker, 5.6-mm "ES4" membrane were smaller than those of for the thinner 4.8-mm "ES3" membrane.

The test reports from the laboratory indicate that, in all cases, there was some elongation of the membrane at the grips on the edges. Also, the photo logs of the membrane after the tests show that the granular material got partially embedded into the bitumen and the horizontal movement of the upper box dragged the bitumen along, thus partially exposing the reinforcing geotextile. This could indicate that the shear stresses recorded during the test are somehow affected by the tear resistance of the geotextile and/or by the resistance of the internal interface between the bitumen blend and the geotextile.

After consultation with a geosynthetics consultant, it was decided to run a non-standard "floating" direct shear test (i.e., without clamping the membrane sample at the sides) with the membrane placed between the overliner and the subgrade (instead of the steel grip plate). The logic behind this test was that, given the usually large dimensions of a real-life pad, the effect of the anchoring of the membrane at the borders of the pad would have little or no impact on the behavior in the middle of the pad. The "floating" direct shear test was done at the same normal loads as the other tests (i.e., 500, 1,000 and 2,100 kPa). Shearing occurred at the geomembrane – subgrade interface (i.e., at the smooth Terphane side of the membrane) at the three normal loads tested. No dragging of the bitumen on the upper side of the geomembrane was observed. The friction angles obtained from this "floating" test were 8.5° for the peak stress and 8.3° for the large displacement. friction angle. These results make us think that the friction angles of the sanded side of the BGM should be actually higher than those derived from the linear envelopes of the initial tests. In our view, the friction angles obtained under this program must be used with caution and further investigation on this matter is required.

3 CONCLUSIONS

Based on the results described above the authors concluded that:

Both the 5.6 mm-thick BGM and the 4.8 mm-thick BGM tested can withstand the puncture loads imposed by the proposed heap leach with a safety factor larger than 2.8 and thus are deemed suitable for the application from this point of view,

The puncture resistance of both BGM's against the mineral to be leached is as good (or maybe better) than the puncture resistance against the overliner. This may lead the design engineers to consider that, provided that the mineral to be leached has enough hydraulic conductivity to appropriately transport the leachate, the overliner could be eliminated altogether, thus resulting in large cost savings for the project,

The actual friction angle of the sanded side of the BGM could be higher than the figures derived from the linear Mohr-Coulomb's envelopes from these tests. In our view this is an aspect that requires further investigation.

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