

Key points:

- 1. GCL s can be a very cost effective way of producing a liner that will work well in a wide variety of conditions
- 2. GCLs are not all the same even from a given manufacture. While there may be some application where all will work, there are others where the choice of GCL is important and the right GCL should be specified even if it cost a little more. It is cheaper to do it right in the first place and the onus is on the designer, not the manufacturer, to select the right GCL.
- 3. As with all engineering materials construction practice is also important starting with making sure that the contaractor does supply the right GCL (ie. Does not substitute a cheaper and less suitable GCL), that the GCL is placed correctly, and suitable protexted after placement.

Topics Last Talk

Service life of HDPE A framework for selection of GMB Estimating Service Life of GMBs

Topics in This Talk

Factors in the selection of the type of geomembrane Bituminous geomembranes and HDPE LLDPE and HDPE The many faces of HDPE

Geomembranes for containment of mine waste may be used in

- 1. Lining lagoons to contain waste liquids.
- 2. Bottom liners.
- 3. Covers.

and the geomembrane may be

- exposed, or
- buried

Geomembranes can be excellent for containment of mine waste, BUT

- 1. All geomembranes have strengths and weaknesses you need to understand both.
- 2. Beware of enthusiastic salespeople they can be
 - very helpful, however
 - they will tell you the good things about their product but not always the limitations.
- 3. Remember if you really want containment, you need more than one line of defence: "all liners leak"

Geomembranes can be excellent for containment of mine waste, BUT

- 1. Ask for proof of claims and check carefully them
- 2. Case studies showing good performance can be misleading
 - P1: "it does not leak!" "
 - P2: "how do you know"
 - P1: "we monitored the water drop over 2 days"
 - P2: "what was the accuracy of your measurement"
 - P1: ± 20 mm
 - P2: "so you can have a leakage of 200,000 L/ha/d and not even know it!"

Geomembranes for containment of mine waste

Commonly considered options:

- High density polyethylene (HDPE)
- Linear low density polyethylene (LLDPE)
- Bituminous geomembranes (BGM)
- There is a range of products in each category, and they will not all behave the same
- There can be a bigger difference between one HDPE and another HDPE or between one LLDPE and another LLDPE than between some HDPE and some LLDPE

Labels can be misleading.

All geomembranes have advantages and disadvantages

Choice of type (HDPE, LLDPE, BGM) will depend on factors such as

- a) Acceptable leakage
- b) Service life
- c) Ease of construction, and
- d) Cost

However, sacrificing (a) and/or (b) to benefit from (c) and/or (d) may have significant long-term consequences

Acceptable leakage

Depends on

- Head, and
- · Potential for holes in the GMB, which depends on
 - 1. Puncture and stress crack resistance of GMB (material) AND integrity of seams. Manufacturer, design and construction
 - 2. Material above and below GMB
 - 3. Construction quality control and assurance
 - 4. Applied stress
 - 5. Exposure to external damage, AND
 - 6. Temperature

The material itself is only ONE of SIX factors listed above

Design, construction & operations



Take home messages

- Do not over generalize based on labels like "BGM", "HDPE", "LLDPE", "PVC" etc. there can be a wide variation in properties and performance depending on the specific product being considered.
- Long-term performance does depend on choice of materials BUT many other factors as well.
- When someone claims "no leakage", "long-life", "puncture resistant", "easy to seam" ask for proof (reputable test data) for the specific product under conditions relevant to your application.
- If its important to you seek expert advice!

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Bituminous geomembranes (BGMs)

 Have been effective in canals & potable water ponds where leakage of 10,000~100,000 lphd is of minor concern.



Diavik Diamond Mine, NWT, - 45°C

Bituminous geomembranes (BGMs)



- Have been effective in canals potable water ponds where leakage of 10,000~100,000 lphd is of minor concern.
- Are being considered for containment applications on the basis that:
 - Since they have worked for canals they should be suitable for containment applications, HOWEVER
 - The allowable leakage for hydraulic structures may be orders of magnitude greater than is acceptable for containment applications where a leakage of 1,000 lphd is a major concern.

Diavik Diamond Mine, NWT, - 45°C

Holes in HDPE initial and as covered







Bituminous geomembranes (BGMs) (Bremner et al. 2016)

- 230,600 m² of BGM + soil used to cover tailings and waste rock in Canada
 39 holes/ha (5 mm to 150 mm diameter) in 2011
- 18.4 holes/ha in 2012





Define over and underliner



Puncture resistance



Туре	Puncture	
Clinton & Rowe	Toughness	Holes⁺
(2000)	(N-m)	
4.1-mm BGM*	2.8 ± 0.3	66
0.5-mm HDPE	8.3 ± 0.4	
1-mm HDPE	12.5 ± 0.5	
1.5-mm LLDPE	11.9 ± 0.8	3
1.5-mm HDPE	13.5 ± 0.3	5
2-mm HDPE	14.2 ± 0.3	

⁺ Performance test poorly graded gravel at 2MPa; 0.6m diameter

Varies from one product to another - do not generalize. Test

*no glass fleece



Bituminous geomembranes (BGMs)

One can get good seams in short term tests, but they can creep to failure in tension (e.g. due to differential settlement)



Diavik Diamond Mine, NWT, - 45°C



Time to Nominal Failure (years) Based on immersion tests

Solution	Water		MSW			
GMB	4.8 mm BGM	2 mm HDPE		4.8 mm BGM	4.1 mm BGM	2 mm HDPE
Ref.	#1	#3		#2	#2	#3
20°C	60	>1500		40	31	1500
30°C	28	420		18	14	390
40°C	15	130		8	7	120

Values are for the geomembranes tested and will vary from one geomembrane product to another.

#1 Samea and Abdelaal (2023a) #3 Ewais et al (2017) #2 Samea and Abdelaal (2023c)

Predicted time to nominal failure in field in contact with mining solution,

t_{NF} at 25°C (Years)

рН	4.8mm BGM#4	1.5 mm HDPE ^{#5}
0.5	140	650
11.5	70	850

#4 Silva et al. (unp), #5 Abdelaal et al. (unp)

Take home messages

 BGMs do not wrinkle significantly in the sun and do not stress crack like HDPE all of which is good

However, contrary to some claims, they

- are just as prone to construction damage as HDPE
- need as much care with subgrade as HDPE

and have some serious weaknesses

- · seams creep to failure
- material softens in the sun
- has much poorer long-term performance than HDPE when tested under similar conditions

Topics Last Talk

Calculating leakage through liners for tailings Service life of HDPE

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HDPE or LLDPE?

- Perceived greater flexibility of LLDPE than HDPE is a perception mostly based on comparing products of different thicknesses.
- More variability amongst HDPE and LLDPE than between good quality HDPE and LLDPE.
- Most important things are
 - A suitable antioxidant package

and

• An adequate equilibrium stress crack resistance (SCR_m)

Stress Crack Resistance HDPE/LLDPE

Some LLDPE have no yield stress and hence no test BUT some do



HDPE or LLDPE?
Test data on 2 GMBs

GMB/Property	MxC15	LxD15
Resin	HDPE	LLDPE
Std-OIT (min)	160	190
HP-OIT (min)	960	350
SCR _o (Hours)	800	19,000
Break strength (kN/m)	51	55





HDPE or LLDPE?

- Beware of generalizations since they may or may not be true depending on thickness, resin, and additive package.
- Inadequate GMBs can be screened out based on
 - manufacturers specifications,
 - initial off-roll values

BUT

• Potential service-life can not be distinguished from these values.

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Effect of texturing on *t_{d Field}* for MxTB20

Expected time to $t_{d \ Field}$ (years) in MSWL in field These GMBs have the same base resin and AO package

		Smooth	
	Textured	Edge	
20	> 4000	> 4000	
30	1300	2000	STA .
40	310	480	
50	80	130	
Conductive	No	No	

Difference due to larger surface area of textured portion of the GMB Zafari, Abdelaal & Rowe (2023)

Some Recently Studied GMBs

	ONLY difference is conductive layer	
Generic Name	MxTB20	MxTDC20
Std-OIT (minutes)	285	220
% Std-OIT retained @90 days	56%	53%
Conductive?	No	Yes

Effect of Geomembrane Additives on *t_{d Field}*

Expected time to $t_{d \ Field}$ (years) in MSWL in field These GMBs have the same base resin and AO package

	MxTB20	MxTDC20	Para Sa
20	> 4000	610	
30	1300	240	Black
40	310	100	textured
50	80	44	Conductive
Conductive	No	Yes	

Difference due to carbon black used in the thin conductive layer Zafari, Abdelaal & Rowe (2023)

Effect of Solution on $t_{d Field}$ for MxTB20

Expected time to $t_{d \ Field}$ (years) in field These GMBs have the same base resin and AO package

	MSWL	pH=9
20	> 4000	>4000
30	1300	3500
40	310	1100
50	80	400

Solution chemistry can greatly affect service life

Zafari, Rowe & Abdelaal (2023)

Is a GMB that meets requirements of GRI-GM13 suitable for my Mine Waste?

- Maybe, maybe NOT
- Generally, want Std-OIT > 150 -160 min
- Want SCR_m (after 90 days ageing at 55-65°C) \geq 500 hours

and

 If you need more than 150-year service-life (SL), you need a GMB that has been shown through immersion testing in a simulated leachate to have projected SL > required SL

Requirements geomembrane selection for mine wastes

- A good resin
- A good antioxidant package

- Compatible with your mining fluid

- Good additives
- Should meet requirements of GRI-GM13 as a necessary but NOT sufficient condition
- What you need textured? white? conductive? thickness?
- Need immersion test data for candidate GMBs in a simulation of YOUR expected solution
- Projected *t_{NF}* at your long-term operating temperature?

Take home messages

- In addition to temperature, the chemistry of the mining fluid and its interaction with the GMB controls the time to antioxidant depletion and greatly affects service life.
- A GMB may be very good in one solution and poor in another.
- Every GMB-solution t_{NF} is different until proven otherwise.
- Just changing one parameter in the GMB may substantially change its service life.
- Don't use a textured GMB where it is not essential for stability.
- Don't use a conductive GMB until you check the effect of the conductive layer on time to OIT depletion, t_{d} .

If you need more that 150-year service life – you need test data - Plan well ahead

Design stage

- Think about your geomembrane very early in the process
- Immersion testing, even with accelerated aging takes 6 months.
- Add either a reference GMB or reference solution to test matrix
- For reasonable predictions you need at least 12 months data
- 3 months data is good for relative performance testing but will not give you <u>good</u> predictions of time to AO depletion (i.e., usually grossly underpredicts)
- Longer term predictions can be made by Fieldaring 12-month data with a that over a similar period for other GMBs tested for a much longer time and applying a time correction factor.

If you need more that 150-year service life Plan well ahead

Construction

- The GMBs you need
 - are not "off-the-shelf";
 - are specialty products
 - cost more (better resin, antioxidants. and additives)
 - need testing before shipping to your site
 - needs to be used in a design maintaining strains < 3% on the base and < 5% on side slopes
 - must be properly installed, and
 - may need an electrical leak location survey

Barrier Systems can be extremely effective

BUT need

- 1. Appropriate design.
- 2. Consideration of required service life.
- 3. Consideration of potential failure modes and effects.
- 4. Selection of the right materials.
- 5. Good construction and construction quality assurance.

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