Geomembrane puncture protection for tire derived aggregate

Bryce Marcotte, Ian Fleming
University of Saskatchewan, Saskatoon, Saskatchewan, Canada

ABSTRACT
Geomembranes are used in barrier systems for waste containment facilities and are typically placed over a compacted clay liner or geosynthetic clay liner. Due to the rising cost of gravel in some areas, tire derived aggregate (TDA) is often used as a drainage layer. TDA is composed of light vehicle tires that have been shredded into pieces that vary in size, thickness, and contain protruding steel wires. The wires have the potential to puncture the geomembrane unless sufficient protection is placed above the geomembrane. Multiple short-term (24 hour) tests were completed at different applied pressures with varying levels of protection to develop guidelines for puncture protection.

RÉSUMÉ
Les géomembranes sont utilisées dans les site d'enfuisement pour les installations de confinement des déchets et sont généralement placées sur un revêtement d'argile compacté ou un revêtement d'argile géosynthétique. En raison de l'augmentation du coût du gravier dans certaines régions, l'agrégat dérivé des pneus (TDA) est souvent utilisé comme couche de drainage. TDA est composé de pneus de véhicules légers qui ont été déchiquetés en morceaux de différentes tailles, épaisseurs et contenant des fils d'acier en saillie. Les fils ont le potentiel de percer la géomembrane à moins qu'une protection suffisante soit placée au-dessus de la géomembrane. Des tests multiples à court terme (24 heures) ont été réalisés à différentes pressions appliquées avec différents niveaux de protection afin d'élaborer des directives pour la protection anti-crevaison.

1 INTRODUCTION

Synthetic polymer barriers, known as geomembranes, impede contaminant passage between waste containment facilities and the surrounding environment. Often they are placed above a compacted clay liner or geosynthetic clay liner to further prevent the migration of contaminants (Rowe, 2005). Typically a high hydraulically conductive drainage layer is then placed above the geomembrane to control the hydraulic head on the liner from leachate. Coarse uniform gravel has been recommended in past research as a large particle size has been shown to be less prone to biological induced clogging (Fleming et al. 1999, Fleming & Rowe 2004). To prevent short term puncture, and damage during construction, a protection layer is typically placed between the geomembrane and the drainage layer.

Proper selection of a geotextile protection layer for its ability to prevent puncture due to gravel drainage layers has been described by Narejo et al (1996). Furthermore, a number of studies consisting of a 1.5 mm thick high density polyethylene (HDPE) liner and a nonwoven needle punched protection layers with 50 mm coarse gravel indicated that short term punctures could be prevented (Tognon et al. 2000; Brachman & Gudina 2008; Brachman et al. 2014; Abdelaal et al. 2014). However, the long-term strain limits proposed (example 3% by Seeger & Muller, 2003) were exceeded for the specific test conditions.

Giroud & Bonaparte (2001) noted that geomembranes installed with strict quality control can expect about 5 holes/ha for design purposes. A leak detection survey by Nosko & Touze-Foltz (2000) indicated that 12 holes/hectare were common after installation of a drainage gravel layer. All studies evaluated gravel as the drainage aggregate.

Due to the rising costs of aggregate in many parts of Canada, specifically the prairie regions, practicing engineers have been turning to alternative drainage materials such as tire derived aggregate (TDA). The mechanical and hydraulic properties of TDA have been well classified (Adesokan et al., 2016; Benson et al. 2002; Beaven et al. 2006; Hudson et al. 2007; Reddy & Marella 2001) and have shown to behave hydraulically similar to gravel even while subjected to large vertical pressures. However, protruding wires in the TDA result in unique geomembrane protection challenges.

A study conducted by Reddy & Saichek (1998) indicated the importance of protection for TDA. Multiple tests pads which contained different levels of geotextile protection above the liner were constructed. Five passes with an industrial dozer applying 120 kPa of pressure was applied to each pad. One test pad resulted in a puncture, which occurred with a 540 g/m^2 nonwoven geotextile protection layer above the geomembrane. Thicker layers of tires and heavier protection layers were found to limit visible damage to the liner on other test pads under construction, although no other punctures were observed.

A laboratory component was completed by Reddy & Saichek (1998) to complement the field testing. A 540 g/m^2 nonwoven geotextile protection layer with a 1.5 mm HDPE geomembrane was placed above an elastomer pad and TDA was randomly placed on top. Load was applied in 205 kPA increments in 30 min intervals to a pressure of 1026 kPa and held for 48 hours. Only two replicated tests were completed. No puncture of the geomembrane occurred in the simulated liner loading. Reddy & Saichek (1998) indicated that the orientation of the tire chips resulted in different mechanical geomembrane properties after testing. Furthermore, they warranted caution from the results due to the random nature of the tire shreds.

It is the objective of this paper to provide clearer guidance on suitable puncture protection for TDA under simulated landfill load conditions. It should be realised that TDA quality varies due to manufacturing process, number of passes through the processor, and sharpness of cutting blades, and therefore caution and judgement should be applied when extrapolating the data presented to different TDA sources. Furthermore, this research at the current time gives no indication on the long-term effects of strain and resulting potential for stress cracking due to TDA.

2 EXPERIMENTAL PROGRAM

2.1 Testing Apparatus

A large pneumatic testing apparatus, as shown in Figure 1, was designed to accommodate the large size of TDA. The diameter of the test specimen is 900 mm. Pressure is applied by four pneumatic cylinders and monitored through a low-profile load cell placed in the centre axis between the piston rod plate and the load platform.

Figure 1: Large pneumatic simulated landfill loading testing device

Due to the large vertical strain (>60%) TDA undergoes when subject to high vertical loads, Pistons capable of large stroke were selected. A swivel joint was designed between the load plate and the load cell to ensure no eccentric forces on the load cell occurred and to account for any differential settlement of the TDA.

2.2 Materials

Clay was sourced locally 20 km north of Saskatoon and consists of a silty Battleford Till. Index properties are given in Table 1 and are consistent with Sauer et al. (1993).

Table 1. Characteristics of tested soils

Characteristics (%)	Battleford Till
USCS Classification	CL
Specific Gravity	2.73
Water content[1]	11.8 (Average)
Liquid limit	26.5
Plastic limit	14.3
Std. Proctor Max Dry Density	1980 kg/m^3
Optimum Water Content	10.5
Activity	0.65
% Sand	50
% Silt	35
% Clay	15

[1]water content of specimens after preparation

The TDA samples were sourced from Alberta, CA, and grain size is presented in Figure 2. Two different degrees of processing are presented. In Sample 1 (average length 96 mm), the large pieces are re-passed through the shredder for a second time, reducing the grain size. Sample 2 contained larger TDA tires that are only subject to one pass through the shredder (average length 472 mm).

Grain size analysis is performed by hand through measurement of the length, width, thickness, mass, and by characterizing the wires for each individual piece. Figure 2 represents the diagonal length of the two longest side lengths for each TDA piece as the “sieve” diameter. The average TDA thickness was 11.5 mm.

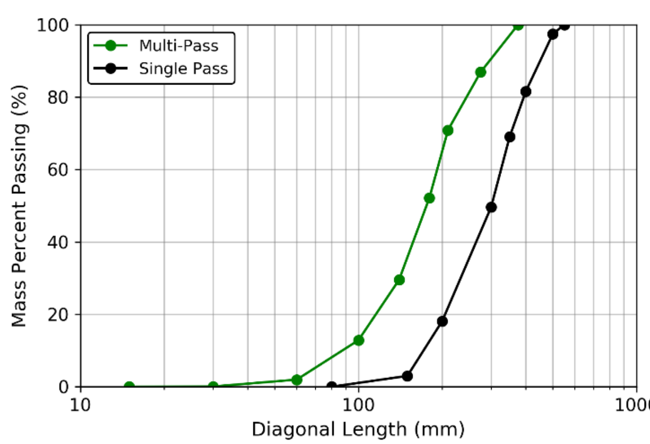

Figure 2: Grain size distribution of TDA used in testing

As the size of the current testing device is approximately 0.64m^2, 1 hole/test would correspond to over 15,000 holes/ha. Therefore, the current research aims to evaluate if a geotextile protection layer can prevent geomembrane puncture. As indicated by Reddy and Saichek (1998), the protection efficiency depends on the random orientation of puncture. Therefore, the testing procedure used in this study attempted to orient pre-sorted TDA pieces in such a manner as to induce puncture of the geomembrane, thus providing a better evaluation of the protection layer capabilities and limiting the number of tests performed.

A pre-sorted group of TDA pieces from Sample 1, as shown in Figure 3, containing significant protruding wires were selected for testing to increase the probability of puncture. Each piece was spray painted for easy identification.

Figure 3: Pre-sorted TDA pieces from Sample 1 with unfavorable protruding wires placed intentionally on geotextile

For the first set of tests (1-5), only 15 unfavourable pieces were used. However, after no puncture occurred with heavier protection layers (tests 4 and 5), the number of pre-sorted pieces was increased to 40 as shown in Figure 3.

2.3 Procedure

Clay was compacted in three equal 50 mm lifts to 100% standard Proctor Optimum dry density using a large steel compaction hammer weighing 22.5 kg and a diameter of 200 mm. Soil was weighed prior to compaction of each lift to determine bulk density. A steel rolling pin was used to smooth the final surface. Moisture contents were taken and compacted dry density was approximated for each test. Undrained shear strengths were measured using a hand vane to ensure relatively constant soil conditions were achieved prior to each test.

A 1.5 mm HDPE geomembrane and prescribed nonwoven needle-punched geotextile protection layers were subsequently placed above the clay liner. The selection of painted TDA pieces, as described above, were placed in with wires facing directly towards the geotextile / geomembrane in a manner to try to induce puncture of the geomembrane. A separate selection of TDA was then placed around the painted TDA pieces. Sand separated by a thin geotextile was then placed above the TDA to ensure uniform loading by the device.

Pressure was applied in 100 kPa increments in 10 min intervals until a test pressure of 500 kPa was reached. The test was then held at 500 kPa for a period of 24 hours. After 24 hours, load was removed, and the geomembrane was inspected for punctures. Any punctures that were difficult to determine from visual inspection were subject to a vacuum test.

3 RESULTS AND DISCUSSION

3.1 Summary of results

A summary of the tests is given in Table 2. The number of puncture pieces refers to the number of pre-selected pieces for puncture (orange pieces in Figure 3) that were intentionally placed on the liner.

Table 2. Summary of soil conditions and punctures results

#	MUA[1] (g/m^2)	GWC[2] (%)	Su[3] (kPa)	# of Puncture Pieces	# of Punctures
1	542	12.7	93	15	5
2	812	12.2	109	15	3
3	1080	11.7	115	15	2
4	1360	12.2	113	15	0
5	1624	11.8	110	15	0
6	1360	11.3	130	40	4
7	1624	11.7	130	40	2

[1]MUA - geotextile mass per unit area; GWC – gravimetric water content; Su – undrained shear strength

After test 4 and 5 were complete, and no holes were observed, a larger selection of 40 pre-selected puncture pieces (as shown in Figure 3) were placed above a 1360 and 1624 g/m^2 geotextile protected geomembrane. Through subsequent tests (6 and 7) it was determined that the heavier geotextile protection layers were not capable of preventing puncture from TDA. Images from the puncture testing are given in Figures 4 through 10.


Figure 4: Punctures from test 1 (top view)


Figure 5: Puncture from test 1 (bottom view)


Figure 6: Puncture from test 2


Figure 7: Puncture from test 2

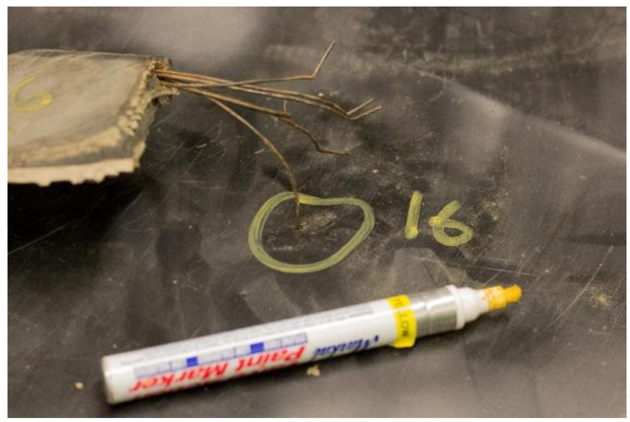

Figure 8: Puncture from test 3


Figure 9: Puncture from test 3

Figure 10: Punctures from test 6

Most of the observed punctures were due to small, 1-2 mm diameter wires as opposed to the thicker tire “bead wires”. A bead wire puncture was observed in test 2 as shown in Figure 7. The lack of beadwire punctures in tests 3 through 7 may indicate that the thicker geotextiles are sufficient in prevent puncture from the large diameter bead wires. The reduction in puncture with increased diameter would be consistent with the findings of Koerner and Koerner (2010) for a given applied load.

3.2 Probability of protection layer punctured when placed in unfavourable positions

By dividing the number of punctures by the number of selectively placed puncture pieces above each protection layer, a relative probability of puncture (given that the TDA falls in an unfavourable manner) can be determined as given in Figure 11. “Unfavourable” will herein describe TDA pieces that fall in such an orientation that the protruding wires are oriented near perpendicular with the geotextile and geomembrane.

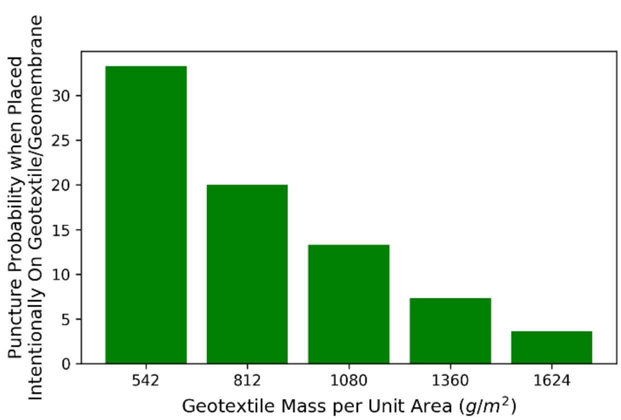

Figure 11: Probability of puncture given that the TDA piece falls in an unfavourable position

It must be emphasized that Figure 11 only describes the probability of puncture given that the TDA particles fall unfavourably since TDA pieces were placed intentionally. For example, as given in Figure 11, approximately 20 punctures for every 100 pieces that falls in an unfavourable manner above an 812 g/m^2 geotextile protected 1.5 mm HDPE geomembrane would be expected to occur.

The data provided in Figure 11 demonstrates that a heavier geotextile protection layer reduces the number of punctures of the geomembrane.

3.3 Probability of high risk TDA pieces

A large selection of TDA pieces was acquired from a representative batch of TDA. Each piece was visually inspected and sorted based on wire puncture potential. Each piece that contained a rigid protruding wire was classified as high medium, or low risk for geomembrane puncture, as shown in Figure 12, based on the observed punctures from the previous large-scale testing.

Figure 12: From left to right: high-risk, medium-risk, and low-risk TDA for puncture of geomembrane

Low-risk pieces contained bead wire protrusions (multiple wires close together to form a large diameter spike) as they were found not to cause puncture when heavier geotextile protection was used. High-risk pieces contained small diameter individual wires as they were found to cause numerous punctures, such as the puncture given in Figure 6, even when heavier geotextiles were used. The selection of high risk wire pieces is given in Figure 13.

Figure 13: High risk TDA pieces containing isolated small diameter wires

Medium risk was defined as TDA pieces that had bead wire protrusions where the end of the group of wires split apart. For a conservative approach, TDA pieces were classified in the higher risk category for pieces that were borderline between two categories. A summary of the results is given in Table 3 and 4 for Samples 1 and 2 respectively.

Table 3. Proportion of at risk TDA pieces for Sample 1

	No risk	Low risk	Medium risk	High risk
# of pieces	1323	17	21	25
% of Total	95.5%	1.2%	1.5%	1.8%
Mass (kg)	134.0	3.0	3.6	4.3
Avg. Wire Length		21 mm	26 mm	43 mm
Std. Dev[1]		11.2 mm	13.7 mm	25.8 mm

[1]Std. Dev – Standard deviation

Table 4. Proportion of at risk TDA pieces for Sample 2

	No risk	Low risk	Medium risk	High risk
# of pieces	300	6	9	8
% of Total	92.9%	1.9%	2.8%	2.5%
Mass (kg)	88.8	1.3	2.7	3.7
Avg. Wire Length		19 mm	34 mm	76 mm
Std. Dev[1]		6.4 mm	19.3 mm	19.4 mm

[1]Std. Dev – Standard deviation

If geomembrane puncture was a concern, only pieces near the bottom of the drainage blanket would be at risk for puncture. If one were to assume that only pieces at the very bottom layer were at risk of puncture, the number of pieces could be estimated from the average area of a TDA piece, as pieces most often lay flat (Hudson et al., 2007). Table 5 outlines the following assumptions and calculations.

Table 5. Estimating puncture potential

Characteristics (%)	Sample 1	Sample 2
Average Length (mm)	96	472
Average Width (mm)	48	143
Average Piece Area (mm^2)	4,590	67,353
Pieces per square metre[1]	218	15
Pieces per hectare	2,180,000	150,000
High risk pieces at bottom per hectare	3,924,000	3,700

[1]Assuming all pieces lay flat, and bottom is completely covered in tires

It should be emphasized that Table 5 only provides an estimate on the number of high risk pieces near the liner. It does not provide any indication of the orientation of the wires, or the probability of the wires puncturing through the geotextile protection layer and geomembrane.

Table 5 does indicate that large TDA pieces (although having a higher proportion of at risk pieces) may improve liner performance since less pieces would be near the liner. Altering processing methods to increase shred size may prove valuable in reducing risk of puncture. A comparison of the size of tire shreds is presented in Figure 14.

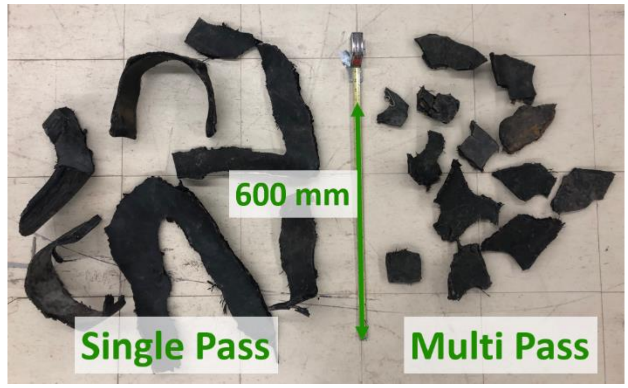

Figure 14: Size differences between single and multi pass

Currently research is underway to determine the probability of TDA pieces landing in a manner that would result in a high chance of puncture. There is a risk of geomembrane puncture from TDA even with a heavier nonwoven needle-punched geotextile protection layer. However, this risk is highly dependent on the probability that the TDA pieces land in such a manner that puncture can occur, and this has not yet been quantified.

4 CONCLUSION

TDA is currently being used as landfill drainage layers above geomembranes. However, there is a risk of puncture of the geomembrane from the protruding wires. This paper presents a preliminary study into both the likelihood of puncture, as well as the proportion of TDA pieces in two different samples which are capable of puncture.

A large scale testing apparatus was used to evaluate puncture of a 1.5 mm geomembrane with varying protection layers when TDA pieces were placed intentionally to puncture. Increasing the mass per unit area was found to decrease the rate of puncture. A majority of punctures were 2-3 mm in diameter from single wires protruding from the TDA. No nonwoven geotextile protection layer in the current study was found to eliminate TDA punctures.

A large sample of TDA was then hand sorted to assess the proportion of TDA pieces that contained wires capable of puncture, and it was determined that around 2% of the tire shreds contain hazardous wires.

The current research fails to fully quantify the risk of TDA to geomembrane liner systems as the rate of the TDA pieces landing in an unfavourable manner (from the perspective of the geomembrane) is still unknown. At the current time, TDA poses a risk to landfill components that is still uncertain.

Increasing the size of the tire shreds by altering manufacturing methods (reducing number of cuts made to tires) may reduce the chance of puncture by TDA.

Further research is required and ongoing to determine the optimum protection layer as well as the anticipated holes per hectare.

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