Effect of Geotextile Static Puncture Strength Value on the Geotextile-Geomembrane interface shear characteristics

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ABSTRACT: Over the past decade, the use of geosynthetics has gained popularity due to their ability improve containment, stability, efficiency, and environmental performance of engineered facilities. However, their utilization has led to the development of interfaces which create potential failure planes within systems. It is therefore imperative to understand the geosynthetics shear characteristics at these interfaces. This study aimed at investigating the impact of the Geotextile California Bearing Ratio (CBR) value on the shear characteristics of the geomembrane-geotextile interface. Several laboratory tests were conducted on different geotextiles with varying CBR values and geomembranes with different asperity heights using the large direct shear test apparatus at different applied pressures ranging from 50kPa up to 800kPa. The results are discussed in detail in this paper.

Keywords: Geosynthetics, Geomembranes, Geotextiles, California Bearing Ratio (CBR), Interface Testing, Shear characteristics.

1 INTRODUCTION

1.1 *Background*

Landfills are usually constructed with basal, slope and cover liner systems that incorporate low-permeability liners and liquid collection layers to prevent leachate migration and contamination of the environment (Ramya Krishna & Harish Kumar Reddy, 2020). These systems often include geosynthetic clay liners (GCLs), high-density polyethylene (HDPE) geomembranes (GMBs), and geotextile (GTX) layers for protection (Koerner, 2005; Bacas, Cañizal & Konietzky, 2015)

According to (Shukla & Yin, 2006) the GCLs are used to reduce leachate migration; the HDPE GMBs act as a hydraulic barrier to prevent contaminant migration, and the GTX placed over the GMB provides protection from potential damages to the geomembrane inform of excessive strains or puncture from overlying drainage stones.

The meticulous design of these components within landfill liner and cover systems are of paramount importance in establishing interfaces that contribute significantly to the overall performance of these systems (Cossu & Stegmann, 2019).

However, the use of these geosynthetic materials in landfill liner systems has led to creation of multiple interfaces which are susceptible to shear failure (Muluti et al., 2023). Its therefore vital to investigate the interface shear characteristics and incorporate them in the landfill liner design.

1.2 *Study Objective*

The main objective of this study was to determine the impact of the geotextile CBR value on the geomembrane/geotextile interface shear characteristics. This was achieved through conducting a critical review of relevant literature, conducting interface shear and repeatability tests using a large direct shear test apparatus as well as analysis and verification of test results.

2 EXPERIMENTAL STUDY

2.1 *Test materials.*

2.1.1 *Geomembranes (GMBs)*

Apart from acting as hydraulic barriers in basal lining systems, geomembranes also restrict the movement of gases such as methane, produced by the decomposition of organic waste especially in the landfill cover liner (Rowe & Yu, 2019; Touze-Foltz, Xie & Stoltz, 2021; Marcotte & Fleming, 2022).

In this study, 2mm thick, High-Density Polyethylene (HDPE) geomembranes with varying surface textures/asperity heights, and locally manufactured in South Africa were used. The test specimen included a smooth geomembrane (GMB 1), micro textured geomembrane (GMB 2) with 0.65mm asperity height and mega textured geomembrane (GMB 3) with 1.8mm asperity height as shown in Figure 2-1. The key properties of the geomembranes used in this study are indicated in the Table 2-1.

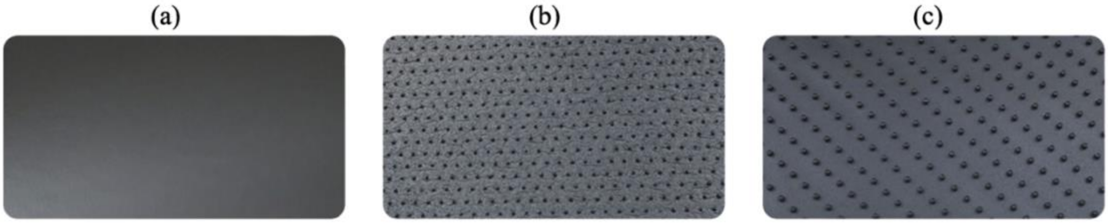

Figure 2-1: (a) Smooth Geomembrane, b) Micro textured Geomembrane, c) Mega textured Geomembrane (Adopted from manufacturer)

Table 2-1: Geomembrane Properties (Source: Manufacturer)

Geomembrane Property	**Units**	**GMB 1 (Smooth)**	**GMB 2 (Micro)**	**GMB 3 (Mega)**
Thickness - Minimum Avg.(a)	mm	2.0	2.0	2.0
Asperity Height – Minimum Avg	mm	0.0	0.65	1.80
Formulated Density	g/cc		≥0.94	
Yield Strength	kN/m	29	29	29
Break Strength	kN/m	53	21	21
Yield Elongation	%	12	12	13
Break Elongation	%	700	300	250
Tear Resistance - Minimum Avg.	N	249	249	249
Puncture Resistance - Minimum Avg.	N	640	534	550

2.1.2 *Geotextiles (GTXs)*

Geotextiles can be used for filtration, separation, drainage, protection as well as reinforcement in landfill liner systems (Brachman, Asce & Sabir, 2013; Hornsey, 2013; Austin, Gibbs & Kendall, 2014; Karademir & Frost, 2021).

Two sets of non-woven needle-punched geotextiles, GTX 1-3 (set 1) and GTX 4-6 (set 2) from two different South African local manufacturers with varying CBR value as obtained from the static puncture strength test were used in this study. These geotextiles were sheared against the geomembranes with varying asperity heights to investigate the effect of the CBR value on the GTX/GMB interface shear characteristics.

The material properties of the first set of geotextiles (GTX 1-3) used in the study are highlighted in the Table 2-2. Figure 2-2 below shows the first set of the geotextiles used .

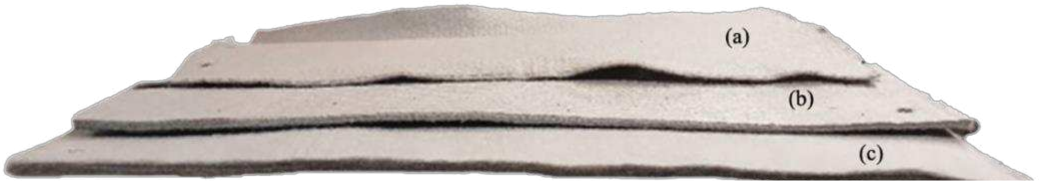

Figure 2-2: (a) GXT 1), (b) GTX 2, (c) GTX 3

Table 2-2: Material properties of set 1 Geotextiles, GTX 1-3 (Source: Manufacturer)

Geotextile Property		**Units**	**GTX 1**	**GTX 2**	**GTX 3**
Mass	Nominal	g/m^2	400	750	1200
Thickness	At 2 kPa	mm	3.4	5.5	7.0
Static Puncture Strength	CBR Test	kN	4.50	9.80	14.0
Tensile Strength	MD/CMD	kN/m	25.0/28.0	55.0/60.0	75.0/75.0
Water Flow	50mm Head	l/s/m^2	42	23	15

The second set of the geotextiles comprised of GTX 4-6, as shown in Figure 2-3 below. The material properties of these geotextiles are highlighted in the Table 2-3

Figure 2-3: (a) GTX 4, (b) GTX 5, (c) GTX 6

Table 2-3: Material properties of Set 2 Geotextiles GTX 4-6. (Source: Manufacturer)

Geotextile Property		**Units**	**GTX 4**	**GTX 5**	**GTX 6**
Mass	Nominal	g/m^2	340	750	1000
Thickness	Under 2 kPa	mm	3.1	5.4	7.0
Static Puncture Strength	CBR Test	kN	4.8	9.5	11.7
Tensile Strength	MD/CMD	kN/m	26/26	50/50	56/56
Water Flow	50mm Head	l/s/m^2	70	36	25

2.2 *Test procedure*

The geosynthetic materials were cut into equal 500mm by 300mm test specimen along the Machine Direction (MD) as indicated by the manufacturers. Holes were punched in the test specimens which were then clamped onto the top and bottom box of the machine as shown in Figure 2-4 below. The top box was then centred on top of the bottom box using alignment screws and assembled into the LDST equipment.

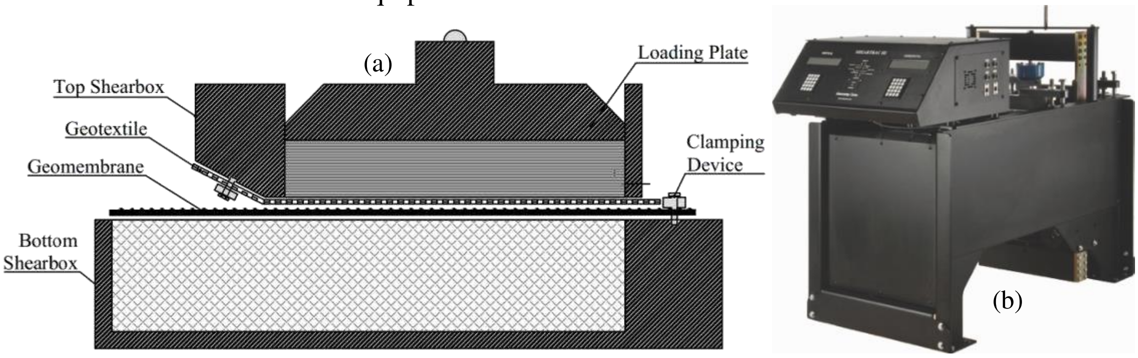

Figure 2-4: (a) cross-sectional view of the GTX/GMB setup (b) Large Direct Shear Tests Equipment (LDSTE)

The interface tests were conducted in accordance with ASTM D5321-12 using a well calibrated Large Direct Shear Equipment. Five different normal stresses namely, 50kPa, 100kPa, 200, 400 kPa, and 800kPa were applied to simulate the landfill incremental loads during its service life. Tests were conducted in a saturated state, at a shearing rate of 1.0mm/min. The total displacement at end of the test was 75mm. A total of 90 interface tests were conducted as shown in the Table 2-4.

Table 2-4: GTX/GMB Interface testing configuration

Set No.	Interface material configuration	Applied Normal stresses (kPa)	No of tests
SET 1	GMB 1 vs GTX 1, GTX 2, GTX 3	50, 100, 200, 400, 800	15
	GMB 2 vs GTX 1, GTX 2, GTX 3	50, 100, 200, 400, 800	15
	GMB 3 vs GTX 1, GTX 2, GTX 3	50, 100, 200, 400, 800	15
SET 2	GMB 1 vs GTX 4, GTX 5, GTX 6	50, 100, 200, 400, 800	15
	GMB 2 vs GTX 4, GTX 5, GTX 6	50, 100, 200, 400, 800	15
	GMB 3 vs GTX 4, GTX 5, GTX 6	50, 100, 200, 400, 800	15
		Total	90

3 RESULTS AND DISCUSSION

3.1 *Test results.*

Peak and Large Displacement (LD) interface shear results from each GMB/GTX combination were obtained from the test data and are summarised in Table 3-1 below.

Table 3-1: Peak and Large displacement GTX/GMB interface shear test Results

Set	Normal Stress, kPa		50	100	200	400	800	50	100	200	400	800
No.	GMB/GTX Test		Peak shear stress values (kPa)					Large displacement shear stress (kPa)				
Set 1	GTX 1	GMB 1	9.4	17.8	30.9	68.4	129	7.45	13.4	24.5	47.2	92.1
		GMB 2	30.5	58.2	114	209	371	25.1	45.7	72.9	117	156
		GMB 3	36.9	68.6	120	245	411	26.2	41.9	82.9	147	204
	GTX 2	GMB 1	8.35	17.6	33.0	70.3	136	7.9	14.6	28.7	60.8	105
		GMB 2	29.4	58.8	114	211	351	27.4	52.5	60.8	93.6	168
		GMB 3	44.8	79.2	155	329	495	32.7	53.9	88.2	132	199
	GTX 3	GMB 1	7.84	13.8	32.8	59.5	122	6.47	12.6	28.2	45.1	89.0
		GMB 2	30.4	60.4	108	205	372	27.4	48.0	88.9	141	176
		GMB 3	40.9	85.6	158	312	502	27.2	50.4	85.7	149	216
Set 2	GTX 6	GMB 1	16.2	30.4	47.4	102	190	12.6	22.9	39.0	80.1	151
		GMB 2	34.6	65.5	121	243	434	26.2	50.6	87.7	158	216
		GMB 3	36.4	72.3	125	254	495	28.9	52.2	100	163	257
	GTX 5	GMB 1	15.5	28.9	47.5	92.4	196	12.0	20.1	38.1	78.7	160
		GMB 2	37.5	69.2	166	294	450	29.7	48.5	87.8	123	214
		GMB 3	47.3	78.9	153	305	545	32.8	54.3	96.1	159	262
	GTX 6	GMB 1	15.2	25.1	49.4	93.9	185	11.1	19.2	38.4	81.7	155
		GMB 2	38.7	76.3	148	241	461	25.0	51.2	68.9	122	215
		GMB 3	39.2	74.8	156	284	566	25.8	59.0	97.8	165	262

**GBM1-Smooth Geomembrane, *GMB2- Micro textured Geomembrane, *GMB3-Mega textured Geomembrane*

3.2 *Results analysis and discussion*

3.2.1 *GTX/GMB Shear stress vs horizontal displacement.*

Using the results from the tests, the shear stress versus horizontal displacement graphs for all the GMB/GTX configurations were plotted. Some of these have been included in Figure 3-1.

From the shear stress vs horizontal displacement plots, it was observed that the peak shear stresses occurred at displacements of less than 20mm with a distinct peak in all tests. Beyond the peak shear stress values, there was a reduction in the stress values ranging from 5% to 60%, leading to a final large displacement shear stress at 75mm. These results were found to be consistent with the findings by other researchers including (Buthelezi, 2017; Sikwanda, 2018; Muluti, 2021).

Increasing the normal stress resulted into an increase in the observed peak and large displacement shear stress values. This is because applied normal stress creates more resistance during shearing leading to higher shear stress values.

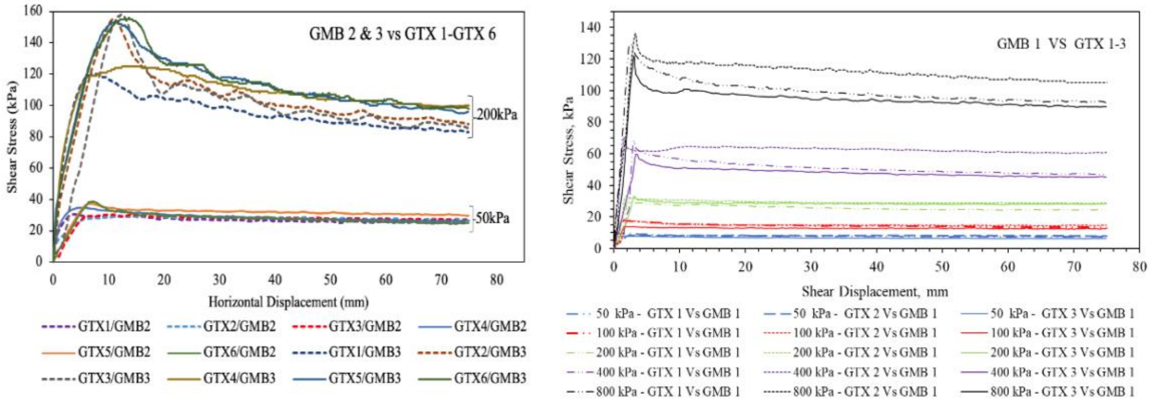

Figure 3-1: GTX/GMB Shear stress vs horizontal displacement plots.

3.2.2 *Test repeatability.*

To ensure reliability of the test procedure and results, a number of tests were repeated at random, and the percentage difference between the results was found to be within recommended 10% of the original value (ASTM, 2012; Muluti et al., 2023). Some of the repeatability plots and the original test plots are shown in Figure 3-2 below.

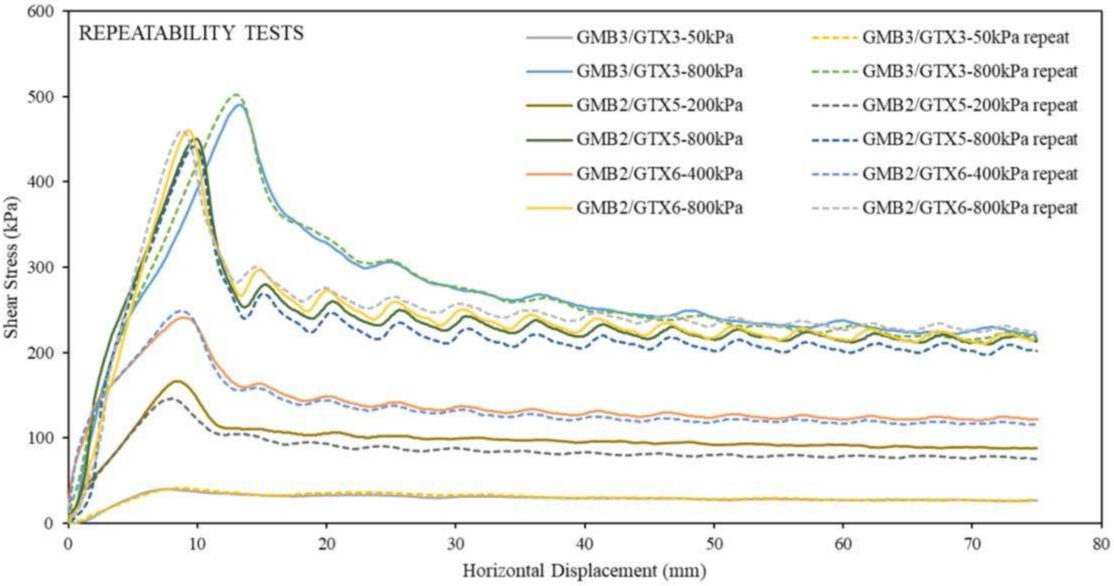

Figure 3-2: Shear stress vs horizontal displacement plots for repeatability tests.

3.2.3 *GMB/GTX interface and peak/LD shear strength values*

From Table 3-1 and Figure 3-3, it can be observed that the mega texture geomembrane (GMB 3) with asperity height of 1.8mm developed the highest shear stresses while the smooth geomembrane (GMB 1) developed the lowest shear stress irrespective of the geotextile type. This was mainly attributed to the interlocking of the geomembrane asperities with the geotextile fibres thereby increasing the resistance to shearing.

Peak Shear stress values were plotted against the normal stress and a line of best fit drawn as shown by the plots of GTX 1 vs GMB 1 and GTX 3. Vs GMB 1 in Figure 3-3.

However, at higher applied normal pressures, it was observed that the shear stress versus normal stress plots became curvilinear particularly with increase in geomembrane asperity height which was typical of GMB 2 and 3 as shown in Figure 3-3. This was attributed to the strain softening (decreased stiffness with increased strain) of the geomembrane asperities (Buthelezi, 2017). The curvilinear nature was not present/less pronounced in the interface tests involving the smooth geomembrane.

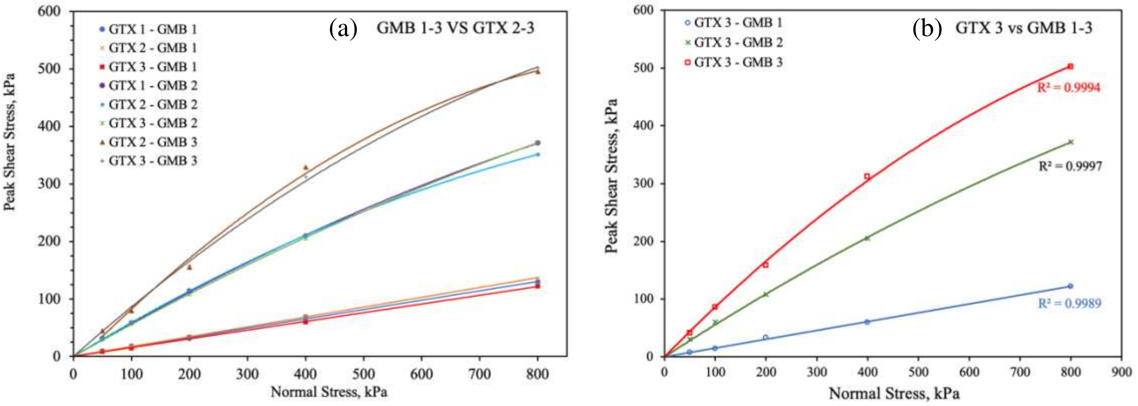

Figure 3-3: Peak shear stress vs normal stress plots for various GTX/GMB combinations.

3.2.4 *Influence of CBR Value on interface shear characteristics*

The test results indicated that variation in the CBR value of the geotextiles had no significant effect on the GMB/GTX interface shear strength characteristic as shown in Table 3-1 and Figure 3-3 (a) above. This is in agreement with the findings from Adeleke et al., (2020) who observed that the GTX/GMB interface characteristics are mainly governed by the properties of the geomembrane such as asperity heights.

3.2.5 *Influence of the GMB properties on the interface shear characteristics*

From Figure 3-3 (b), it can be observed that the GMB/GTX interface shear characteristics are mainly driven by the geomembrane properties such as surface texture and asperity height. As the asperity height of the geomembrane increased, the peak shear stress values increased for example, at a normal stress of 800kPa, the peak shear strength values were 122kPa for GTX3/GMB1, 372kPa for GTX3/GMB2 and 502kPa for GTX3/GMB3 interface tests. A similar pattern was observed for all the GTX/GMB combinations tested indicating that the geomembrane asperities were the main factors influencing the GMB/GTX interface shear characteristics.

4 CONCLUSIONS

The peak shear stress for the geomembrane-geotextile interface was achieved within horizontal displacement of 20mm for all tests conducted and reduced by 5% to 60% at large displacement. The study underscores the direct relationship between the geomembrane asperity heights and interface shear characteristics. An increase in the asperity heights was observed to lead to an increase in shear stress irrespective of the CBR value of the geotextiles used.

From the test results, it can be concluded that the geotextile CBR value has no significant impact on the GTX/GMB interface shear characteristics. The geomembrane properties such as asperities were found to be the driving factors in the GTX/GMB interface tests.

Other considerations such as protection efficacy of the geotextile from inducing excessive strains in the GMB should be considered and studied further to ensure long term serviceability of the geosynthetics in landfill liners. It is expected that the CBR value of the geotextiles will play a vital role in the protection efficacy but not the interface shear characteristics of the GTX/GMB.

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