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A Comparative Study on the Effects of the Geotextile Thickness to the Geotextile and Geomembrane Interface

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Abstract

This study investigates the effect of recycled polyester fibered geotextile (GTX) thickness on the interface shear strength with textured geomembrane (GMB) in landfill liners. Using ASTM D5321 standards, direct shear tests were performed at normal pressures from 50 kPa to 800 kPa. The results exhibited a non-linear horizontal shear stress-displacement relationship, with peak shear strengths occurring within 0 to 15 mm displacement. Peak shear stress diminished by 5-47% with increasing load and stabilized beyond 15 mm displacement. Analysis across GTX thicknesses indicated a 16.5% average increase in peak shear strength from the thinnest to the intermediately thick GTX for textured GMB, followed by a decrease from the intermediately thick to the thickest GTX. These results highlight the importance of optimizing GTX thickness to enhance interface shear strength, thereby aiding in the selection of cost-effective GTX thicknesses to ensure high-quality GMB/GTX interaction in landfill liner systems.

Keywords: *Geomembrane, Geomembrane/Geotextile interface, Geotextile, Landfill liner system, Shear strength.*

1 Introduction

This thesis focuses on the use of geosynthetics in landfill liner systems in South Africa, primarily to control the flow of liquids and protect groundwater from harmful substances found in solid waste. It emphasizes the importance of safeguarding geomembrane linings to prevent leakage of toxic liquids into groundwater. Guo et al. (2021) mentioned that geotextiles are hydrophobic, non-wicking geotextiles, particularly woven ones, cannot wick water under unsaturated circumstances. The degree of saturation of a geotextile, like soil, has a substantial influence on its drainage efficiency. This research specifically explores the interaction between the geomembrane and geotextile interface within these landfill liner systems, which often consist of multiple layers, (Bouazza et al., 2002; Sikwanda, 2019). The South African Government's Department of Water Affairs and Forestry's Minimum Requirement for Waste

Disposal by Landfill, (DWAF, 1998) emphasizes the importance of cost-effective and environmentally sound landfill design. This underscores the significant role that geosynthetics can play in achieving these goals. Over the past four decades, landfilling processes have evolved to meet stringent environmental regulations, as highlighted by Pathak et al. (2020). However, challenges persist, particularly concerning leachate, posing a threat to surface water and groundwater quality, (Iravanian & Ravari, 2020). Under these circumstances, a lining system, consisting of an impermeable geosynthetic layer would be effective to protect the underground water from being intoxicated. On the other hand, according to Pathak et al. (2020), placing a low permeability synthetic membrane, such as a geomembrane, would be ineffective if physically defected. Geomembranes provide excellent liquid barrier properties but are vulnerable to damage from sharp objects due to the weight of waste and drainage gravel. Geotextiles, while lacking water resistance, help retain solids and protect geomembranes. Thicker geotextiles offer better protection but are less cost-effective and can introduce potential failure points in landfill liners. This study focuses on optimizing the interaction between GMB and GTX by adjusting geotextile thickness to enhance shear strength and cohesion at the interface. The goal was to improve efficiency in landfills and potentially increase geotextile capacity while maintaining cost-effectiveness and hydraulic and protective functionalities. Additionally, in the context of increasing emphasis on sustainable infrastructure, enhancing the performance of the GMB/GTX interface opens broader applications for these materials in construction and landfill projects (Zaharescu, 2018). The laboratory tests performed involved examining how different thicknesses of geotextile samples interact with various asperities of geomembrane samples.

2 Research Materials and Methodology

2.1 Research Material and Assemblage

This study utilized geotextiles A, B, and C, commonly used in South African landfill liners, to replicate field conditions. Table 1 presents the physical, mechanical, hydraulic, and durability characteristics of these geotextiles. These non-woven geotextiles were made up of spatially curved filaments that were randomly orientated and dispersed in the polymer arrangement, (Sikwanda, 2019). Three types of High-Density Polyethylene (HDPE) geomembranes, GMB 1 (smooth), GMB 2 (micro-textured), and GMB 3 (mega-textured), common in South African landfills, were studied. Their mechanical properties were displayed in Table 2. Shear parameters at the geomembrane-geotextile interface were determined using Geocomp Corporation's Shear Trac-III, with a top shear box of 305 mm x 305 mm and a bottom shear box of 305 mm x 405 mm, to accommodate up to 75 mm of shear displacement. Sandpaper, influenced by prior studies (Muluti, 2021; Sikwanda, 2019), were affixed to the lower shear box, enhanced friction during tests. Preparations followed ASTM D5321 standards, with geosynthetics measuring 320 mm x 500 mm for both boxes. Tests employed an aluminium substrate and an additional polypropylene one for normal loads of 400 kPa and 800 kPa respectively. The setup included alignment screws and a sandpaper-lined gripping system, as shown in Figure 1. Testing commenced with a 10 kg loading plate and steel ball positioned over the substrate and test sample assemblage.

Table 1. Properties of A, B and C Geotextile, (Kaytech Engineered Fabrics Ltd, 2020).

Geotextile			A	B	C
Mechanical Properties*	**Test Method**	**Units**	**MARV Values**		
Mass per unit area	SANS 9864	g/m^2	340	750	1000
Thickness**	SANS 9863-1	mm	3.1	5.4	7.0
Grab Strength	ASTM D4632	N	1410	2815	3700
		%	50-80	50-80	50-80
Trapezoidal Tear Strength	ASTM D4533	N	650	1330	1950

Static Puncture (CBR) Strength	SANS 12236	kN	4.3	9.0	11.0
Permeability	SANS 11058	m/s	0.00434	0.00389	0.00350
Pore Size (O_{90}/O_{95})	SANS 12956	µm	119	91	84

*All values are Minimum Average Roll Value (MARV).
**Under 2 kPa.

Table 2. Properties of GMB 1, GMB 2 and GMB 3 Geomembrane, (AKS Lining (Pty) Ltd, 2019).

Geomembrane			GMB 1	GMB 2	GMB 3
Mechanical Properties*	**Test Method**	**Units**	**MARV Values**		
Asperity Height	ASTM D7466	mm	0	0.7	1.8
Thickness	ASTM D5199	mm	1.5	2.0	2.0
Formulated Density	ASTM D1505	g/cc	0.94	0.94	0.94
Puncture Strength	ASTM D4833	N	480	534	550
Tear Resistance	ASTM D1004	N	187	249	249
Carbon Black	ASTM D4218	%	2.5	2.5	2.5

*All values are Minimum Average Roll Value (MARV).

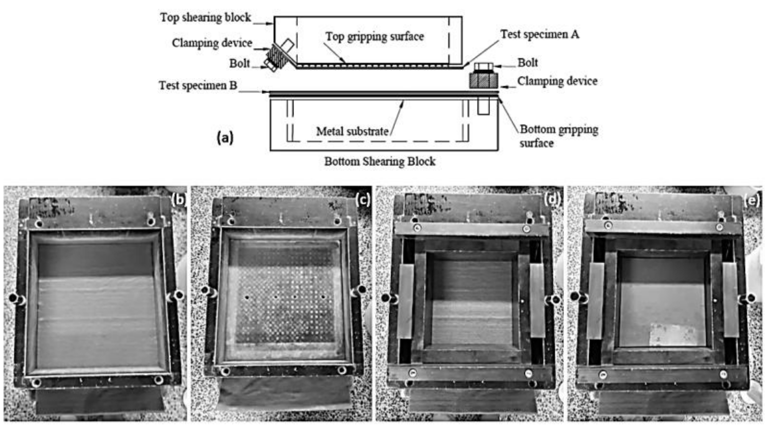


Figure 1. Shear box set-up: (a) Cross section of shear box, (Muluti, 2021); (b) plan view of top shear box; (c) plan view of top shear box with substrate gripping plate; (d) plan view of top shear box for 800 kPa; (e) plan view of top shear box with gripping plate for 800 kPa.

2.2 Test Procedure

The test procedure involved utilizing the Shear Trac-III device with a software application on a computer. Stresses of 50, 100, 200, 400, and 800 kPa were applied to GMB/GTX samples, adhering to ASTM D5321 recommendations. A constant shear rate of 1.0 mm/min was maintained. Maximum horizontal displacement was set at 75 mm, yielding 'Large Displacement (LD)' shear strengths. Specimen sizes varied based on normal stresses, with a consolidation time of 2 min. The shear device was calibrated as per manufacturer's instructions. Tests were conducted under saturated conditions, allowing sufficient time for geosynthetics hydration. A 1 mm to 5 mm gap between shear boxes was maintained to reduce friction, (ASTM D5321, 2017). The Shear Trac-III program collected data from load and displacement LVDTs, storing it in an output file, (Daniel, 2020). Shearing commenced with a tangential force applied to the bottom shear box, monitored for normal force and horizontal displacement.

2.3 Data Processing

After each test, data from the Shear Trac-III were exported to Microsoft Excel for analysis. Graphs depicting shear strength were created, including shear stress vs. horizontal shear displacement and shear stress vs. normal stress. The Mohr-Coulomb failure criterion was determined by connecting shear strength data points using lines of best fit or curves in Excel. The equation, shown below, derived from this criterion was utilized to calculate the angle of friction (from the slope) and cohesion values (from the Y-intercept) at the interface. Graphs were generated for both peak shear strength and LD shear strength.

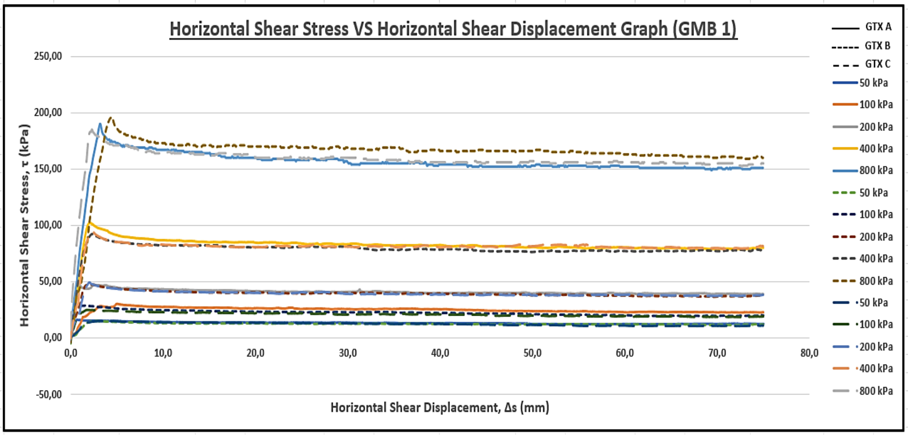
$$\tau = c + \sigma_n \tan(\delta) \quad (1)$$

Where $\tau =$ peak or LD shear strength, $c =$ adhesion corresponding to the inclination of the vertical axis, $\sigma_n =$ applied normal stress, $\delta =$ interface friction angle corresponding to the inclination of the horizontal axis.

3 Test Results Analysis

3.1 Shear Stress and Horizontal Displacement

The study compared three types of geotextiles: GTX A, GTX B, and GTX C, focusing on their shear strength under various normal stresses using GMB 1 and GMB 3. GTX A, the thinnest geotextile, exhibited the highest peak shear strength at 400 kPa normal stress with GMB 1, but GTX B surpassed it at 800 kPa, as shown in Figure 2. GTX C showed lower strength values with GMB 1. GTX A also displayed the least displacement at 50 kPa but had higher displacement at higher normal stresses compared to GTX B. GTX A consistently had lower shear strength compared to GTX B across normal stresses with GMB 1. Regarding horizontal shear displacement, GTX A had the lowest overall, indicating thicker geotextiles were more prone to filament pullout, especially at high normal stresses. With GMB 3, all geotextiles showed increased shear strength, with GTX B performing best at lower normal stresses and GTX C at higher normal stresses. Higher asperity height and thickness were associated with higher shear strength due to increased interlocking.



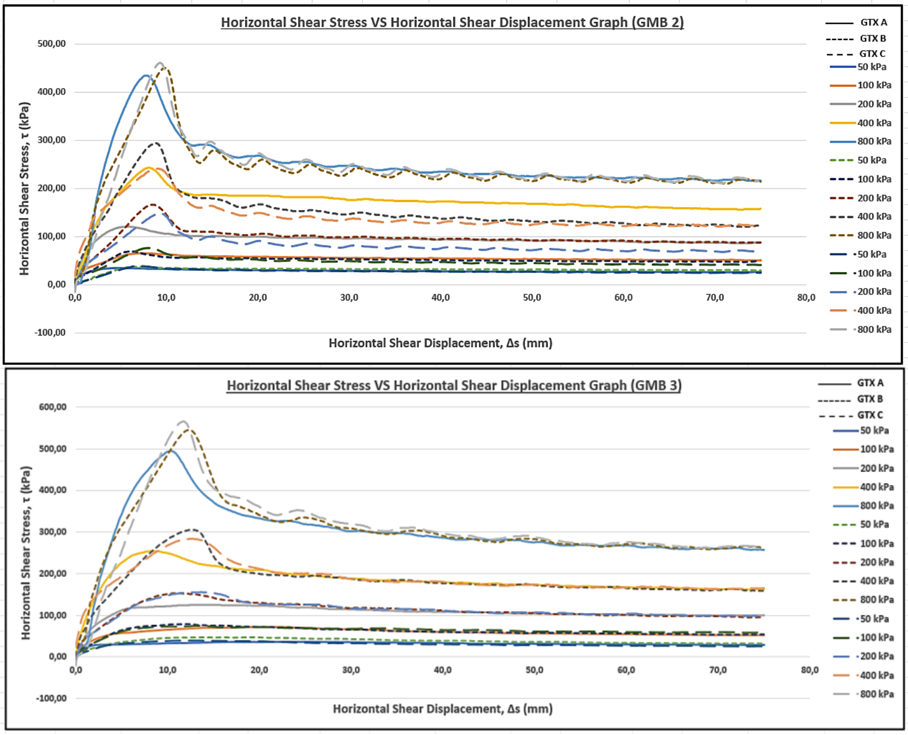


Figure 2. Horizontal shear stress against horizontal shear displacement for different GTX.

3.2 Shear Stress and Normal Stress

Figure 3 showed an example of the shear stress and normal stress applied results obtained for GMB 2. Linear correlations between peak and LD shear to normal stress with GTX B showed the highest friction and lowest adhesion value. GTX A to GTX B exhibited a 2.54% increase in peak shear stress angle, while GTX B to GTX C showed a 4.97% decrease. GTX B's angle of friction decreased by 4.30% compared to GTX A and increased by 4.17% compared to GTX C for peak shear stress. For LD shear stress, GTX B increased by 5.34% from GTX A to GTX B, compared to a 1.79% increase from GTX B to GTX C. GTX C displayed higher efficiency due to its lower adhesion value. GMB 3's peak shear stress correlated linearly with normal stress. GTX C had the lowest adhesion value for LD shear stress. GTX C is identified as the most efficient geotextile to pair with GMB 3.

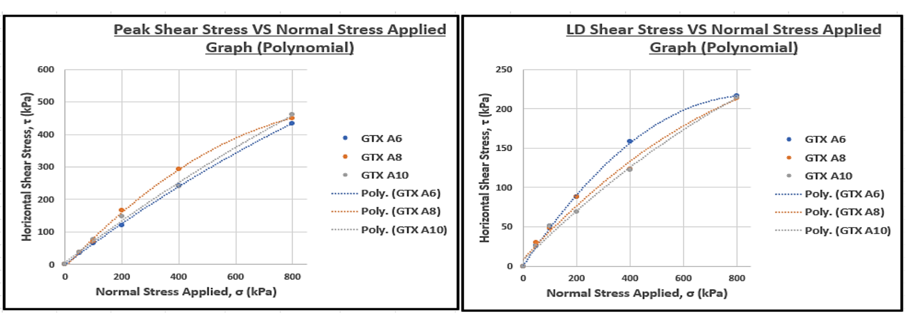


Figure 3. Peak/LD shear stress against normal stress applied results for different GTX.

3.3 Critical Geotextile Thickness Interface

The research analysed shear stress against normal stress graphs to identify the weakest geosynthetic interface in a landfill liner system and determine critical geotextile thickness for system stability. In GMB 1, the angle of friction increased by 2.13% with geotextile thickness from 3.1 mm to 5.4 mm, then decreased by 4.78% up to 7.0 mm, exhibiting its highest peak shear strength with GTX B and the lowest with GTX C. GMB 2 showed a 31.0° angle of friction, 130.1% higher than GMB 1 at GTX A, with its highest peak shear strength at GTX B and lowest with GTX A. GMB 3 displayed a 35.1° angle of friction, 13.14% more than GMB 2 at GTX A, with its highest peak shear strength at GTX C and lowest with GTX A, despite having the highest angle of friction values.

4 Conclusions

The Shear Trac-III apparatus, featuring a 305 mm x 305 mm box size, was employed to study the effect of geotextile thickness on shear strength at geomembrane/geotextile interfaces. Various configurations were tested, including different geotextile thicknesses and geomembrane asperities. Textured geomembranes showed higher average horizontal displacements (4.5–22.5 mm) compared to smooth geomembranes (0.5–5.0 mm) under applied normal stresses. Geotextile thickness influenced displacement, with an increase from GTX A to GTX B, but a decrease from GTX B to GTX C under high normal stresses. Peak shear interface strengths were higher with textured geomembranes, while geotextile thickness had minimal influence on GMB/GTX interface shear characteristics, consistent with previous research (Stark et al., 1996). Smooth geomembranes displayed low strain-softening behaviour.

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