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Asperities effect on polypropylene & polyester geotextile-geomembrane interface shear behaviour

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Abstract. The summary of this paper is focused on the result of a study that used quantitative measures of surface texture as the basis for examining the effects of asperities on the shear characteristics of geotextile-geomembrane interfaces. About 30 large direct shear tests were conducted to evaluate the geotextile-geomembrane interface shear strength properties. The results indicated a non-linear failure envelopes and strain softening behaviour at a normal stress range of 50 – 400 kPa. For most interface tested, the polyester-geotextiles resulted in higher shear strength as compared with polypropylene-geotextiles. Also, the polyester and polypropylene geotextile interface with the high asperity geomembrane produces a similar percentage increase in friction angle at the residual state. For textured geomembranes interfaced with both geotextile, polyester geotextile exhibited relatively less time before failure. Also, asperity height has a more pronounced effect than asperity density on the residual interface shear strength. The outcome of this study would provide a recommendation and guide that can lead to an improved basis for geosynthetics selection in various engineering application.

1 Introduction

Landfills are an important structure in our modern society and are designed to allow maximum accumulation of wastes in the least space and prevent environmental contamination [1]. Landfills usually consist of lining system either as a base liner and/or capping system. The lining systems are made of different geosynthetics including geomembranes, geotextiles, geonets, geosynthetics clay liners (GCL), geomaterials and granular materials usually interacting with each other. Geomembranes, being relatively impermeable, are an integral component of most geo-structures. For instance, geomembranes are used as a hydraulic barrier to minimize pollution in a landfill application. Most importantly, they are used alongside other geosynthetics such as geotextiles and geocomposites for protection and drainage functions respectively. The interaction between different geosynthetics can make or mar the design integrity and stability of the geo-structure [2]. Geomembranes can have an either smooth or textured surface or both. In other words, surfaces with or without asperities. A textured geomembrane with upper and/or lower asperity surfaces is intended to increase the interface shear strength when compared with the smooth geomembrane interface strength. Studies have identified that geomembrane surface asperity influences the shear strength and shear mechanism occurring at the interface [3], [4]. For instance, the geomembrane-geotextile interfaces with hooked asperities recorded approximately 69% increase in shear strength at low (50 kPa) normal stress when compared with the interface without asperities [5]. Surprisingly, it is believed that with a given asperity parameter and high normal stress, polishing and removal of geomembrane asperities and breakage, pull-out, and realignment of geotextile fibres is possible [6]. These could be a major cause for interface shear strength reduction with an increase in displacement. However, studies into the role of asperities on peak and residual strength of the geomembrane-geotextile interface are still limited, and there has been little effort to investigate how variation of asperities height, density, configuration and shape influences both peak and residual strength of a geomembrane-geotextile interface [7].

This paper summarizes the outcome of a study in which the geomembrane texturing and asperity were measured and quantified. A large direct shear device was used to carry out the study. This enables the effect of asperities on the shear mechanism at geomembrane-geotextile interfaces to be investigated. The interface was studied by means of the outcome of thirty different interfaces consisting of three types of geomembranes and two types of geotextile.

In this study, the direct shear tests were carried out based on ASTM D5321 [8]. The relationships examined were the shear stress against horizontal displacement, time to failure against normal stress, and friction angle against asperity parameter.

2 Experimental program

2.1. Introduction

The experiment setup consisted of geomembrane asperity height and density measurement. Asperity height for each textured geomembrane was measured in mm with a dial

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gauge by obtaining the average asperity height of 10 asperities at an equally distributed location on the sheet [9]. Also, asperity concentration/density was measured per 100-millimetre square with a calibrated metal square and mathematically extrapolated to meter square. After quantifying each geomembrane asperity, a series of about 30 large direct interface shear tests were carried out to investigate interface shear behaviour between geomembranes and geotextiles.

2.2 Materials

2.2.1 Geosynthetics

Two different types of nonwoven geotextile were used as shown in Figure 1 below. One was a polypropylene (GXT_P), staple-fibre filament, needle-punched geotextile with a mass per unit area of 400 g/m^2. While, the other was a polyester (GXT_E), staple fibre, needle-punched geotextile with the same mass density of 400 g/m^{2}T. In addition, three different types of 1.5 mm thick high density polyethylene (HDPE) geomembranes (GMB) were used in this study. They are as follows; a flat die extruded double-textured geomembrane and a smooth geomembrane (i.e. no asperity height), with properties as described in Table 1. In Table 1, GMB_{TL} and GMB_{TH} represent a textured geomembrane with low asperity height and textured geomembrane with high asperity height respectively, see Figure 2, while GMB_{SN} signifies a smooth geomembrane which is pictorially illustrated in Figure 3. The materials were tested dry.

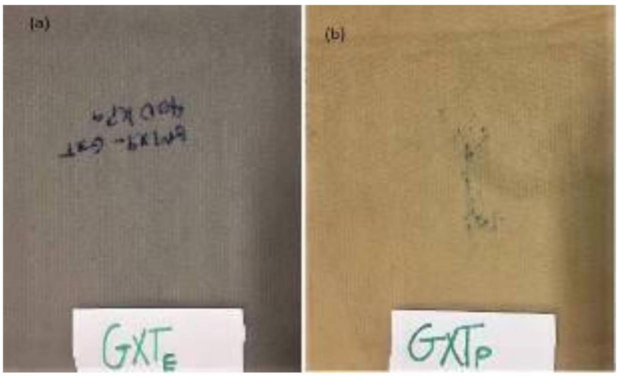

Fig. 1. F-400 geotextile appearance. (a) Polypropylene (b) polyester.

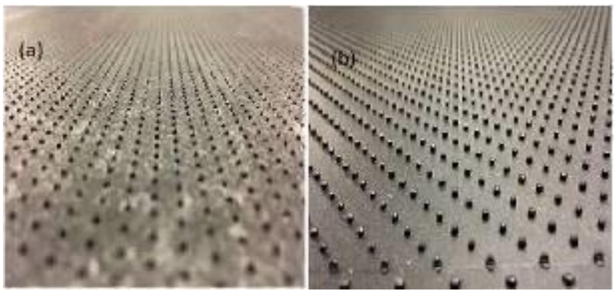

Fig. 2. Textured geomembrane appearance. (a) low asperity height (b) high asperity height.

Fig. 3. Smooth HDPE geomembrane.

Table 1. Geosynthetics details.

Geosynthetics	Label	Polymer type	Density (g/m^2 / g/cc)	Thickness (mm)
Smooth GMB	GMB_{SN}	HDPE	0.94	1.5
Textured GMB	GMB_{TL}	HDPE	0.94	1.5
Textured GMB	GMB_{TH}	HDPE	0.94	1.5
Geotextile	GXT_P	Polypropylene	400	3.4
Geotextile	GXT_E	Polyester	400	3.0

2.2.2 Gripping surface

Gripping surfaces in geosynthetics testing are used to prevent slippage between the device and the geosynthetics and to represent site conditions. In this study, the 3M safety walk sandpaper was used as the gripping surface at both the upper and lower geosynthetics interface with the shear box.

2.3 Direct interface shear tests

In this study, the ASTM-D5321 testing standard was followed to investigate the effect of asperity on the geomembrane-geotextile interface [8]. A large direct shear apparatus developed by Geocomp Corporation Company, USA was used to measure the shear strength of the geomembrane-geotextile interfaces. The device is divided into two main compartments; namely the top static box and the lower moving box. The dimension of the top box and the lower box are 305 mm x 305 mm x 100 mm and 480 mm x 355 mm x 100 mm respectively. The 300 mm x 300 mm large direct device permits a maximum large displacement of 75 mm; hence, all interface tests were programmed to end at 70 mm. This allowed the residual conditions to be obtained around 50 - 70 mm. The tests were carried out at normal stresses of 50, 100, 200, and 400 kPa. The geotextiles were placed on top of the geomembranes in all tests, as this arrangement is a true representative of field conditions. The surface properties of the geomembrane are presented in Table 2. At each interface setup, the normal stress was applied via the leaden plate and then consolidated for 10 minutes. The specimen was sheared at a constant displacement rate of 1 mm/min. These steps were repeated for all investigated interfaces and where the results were inconsistent, the interfaces were re-tested. During shearing, the displacement and shear force was measured by the linear variable differential transformers (LVDTs) and load cell mounted on the apparatus. It is worthy to note that the interface between the smooth geomembrane and the geotextiles serves as a control experiment. This helped in quantifying the effects of asperity on the geomembrane-geotextile interface.

Table 2. Asperity properties.

Surface asperity	GMB_{SN}	GMB_{TL}	GMB_{TH}
Thickness (mm)	1.5	1.5	1.5
Height(mm)	-	0.7	1.9
Density (per m^2)	-	34200	21100
Spacing (mm)	-	5/5	11/5
Configuration	-	Straight	Inclined
Heightdensity ratio	-	0.049	0.13

3 Direct shear test results

In this study, the geomembrane-geotextile interfaces were tested under dry conditions. Because water content does not significantly affect the interface shear strength [10]. For most interfaces tested, peak shear strength is usually attained at about 2 -10 mm displacement, while at 50 -70 mm displacement residual strength is obtained.

3.1 Effect of asperity parameter variation on polypropylene/polyester – geomembrane interface

In this study, the asperity parameters considered are height, density and pattern. Asperities density and height effect were analysed through the plot of interface shear strength against displacement. The interfaces are in two sets, one is polypropylene (PP) geotextile interfaced with geomembrane while the other is the polyester (PET) geotextile interfaced with geomembrane, as differentiated in Figure 4. Although both geotextiles are made from different polymer, their densities were kept constant at 400 g/m^2. Figure 4. below reveals that when asperity height was low (0.7 mm) and increased asperity density, polyester geotextile-geomembrane interfaces exhibited a high peak and residual shear strength at all normal stresses than the interfaces with polypropylene geotextile geomembrane interface. A sound explanation for this observation could be the relative toughness of polyester fabric compared to polypropylene- fabric. Also, the interfaces with polypropylene displayed a large post-peak reduction. In other words, there were sharp transitions from peak strength to residual strength. The cause for this behaviour could be the polymeric material properties of polypropylene geotextile. In a similar vein, when asperity height was high (1.9 mm) with reduced asperity density, similar stress vs displacement curve was exhibited. However, at high normal stress, 400 kPa, both polypropylene and polyester geomembrane interface have quite a similar peak and residual shear strength. Also, the post-peak reduction experienced at the interface was relatively small compared with low asperity geomembrane interface, see Figure 5.

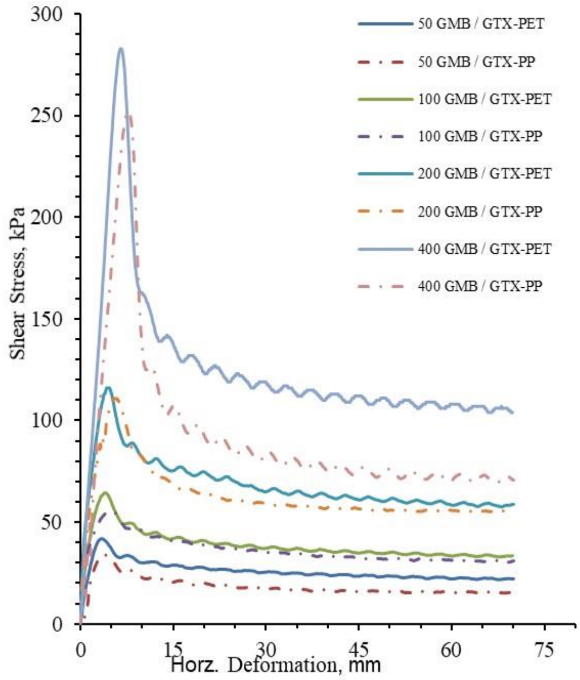

Fig. 4. Comparison of low asperity parameter effect on polypropylene and polyester- geomembrane interface.

3.2 Effect of asperity on failure time at geotextile– geomembrane interface

Failure time of a given interface can be defined as the time elapse measured in minutes for the stress-displacement curve to transit from peak to post-peak value. Studies have shown that failure time is directly proportional to the applied normal stress.

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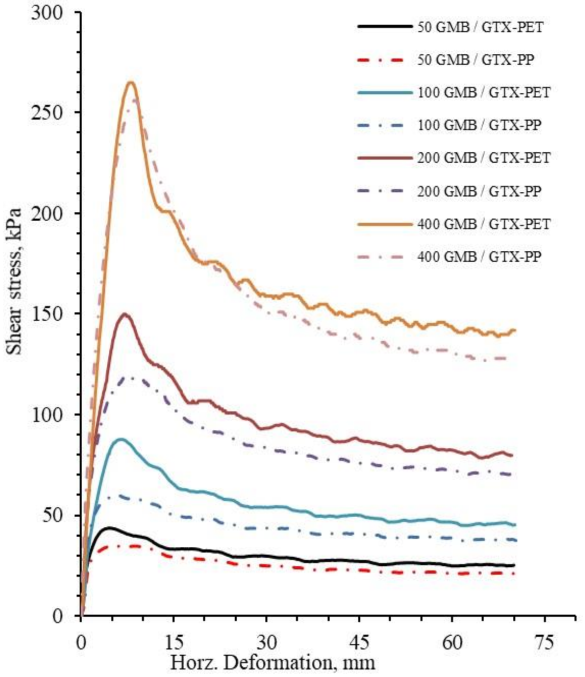

Fig. 5. Comparison of high asperity parameter effect on polypropylene and polyester- geomembrane interface.

Aside from the increase in interface shear strength, the presence of asperity helps to increase the time after which failure can occur. More specifically, asperity height plays a predominant role than asperity density in prolonging the service time before failure. For instance, high GMB/PP, which represent the interface of increased asperity height & low density textured geomembrane and polypropylene geotextile, has the highest service time before failure occurs. Contrarily, the interface with the lowest service time before failure occurs of the six tested interfaces is the reduced asperity height & high density textured geomembrane/polyester geotextile interface, identified as low GMB/PET in Figure 6. On the basis of the interfaces tested in this study, it can be suggested that asperity height is more vital than asperity density towards increasing design life before failure. Also, polypropylene geotextile is preferable for engineering application including landfills if the design is modelled according to serviceability limit state. Polypropylene geotextile has more functional time before failure than polyester geotextile.

3.3 Effect of geotextile polymer

The influence of the polymer types the geotextile is made up of on the geotextile-geomembrane interface can be observed by comparing the friction angles recorded for each different interface. These interfaces can be grouped into two categories namely polypropylene geotextile/geomembrane and the polyester geotextile/geomembrane interface. As shown in Figure 7, smooth geomembrane generally recorded low friction angles. This could be due to the lack of asperities to penetrate the geotextile matrix. Generally, the polyester interfaces exhibited a relatively higher friction angle than the polypropylene interface.

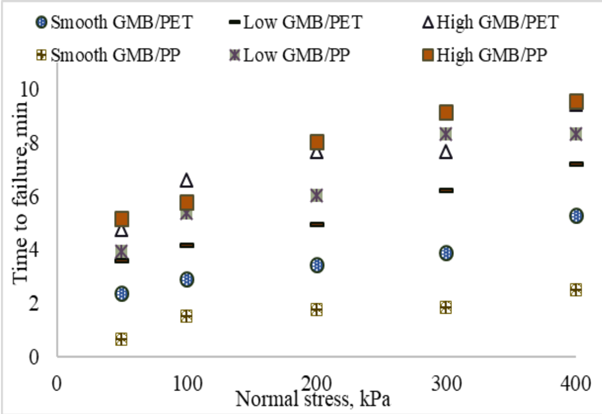

Fig. 6. Comparison of asperity properties on time to failure for polypropylene and polyester- geomembrane interface.

For instance, the residual friction angle of the polyester geomembrane interface is 20% more than the polypropylene-geomembrane friction angle when asperity height is low and asperity density increased.

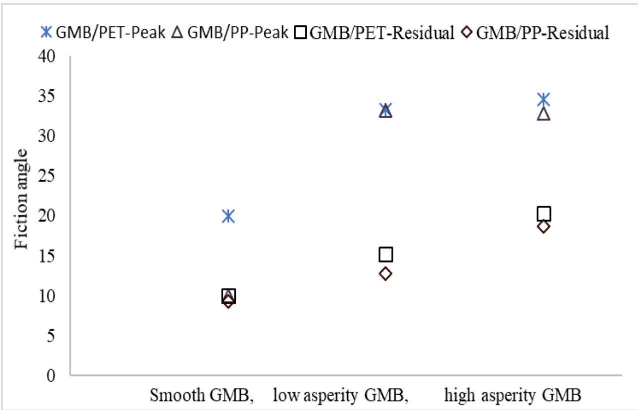

Fig. 7. Friction angle of geomembrane/geotextile interfaces tested in dry conditions.

4 Conclusions

This study has explored with the given scope the influence of geomembrane asperities on geomembrane-geotextile interface strength. The results reveal how significantly a change in the asperity parameter can affect the interface shear behaviour. The following conclusions are based on the data and interpretations presented in the study.

1. Textured geomembranes yield higher peak and residual shear strengths than smooth geomembranes.
2. Polyester geotextile/geomembrane interface most often exhibit higher interface shear characteristics than the polypropylene geotextile/geomembrane interface. Hence should be recommended for applications designed with ultimate limit state theorem.

3. Geomembranes with low asperity height and high asperity density interfaced with geotextile results in excessive post-peak shear reduction. This reduction is more pronounced in polypropylene geotextile.
4. Polypropylene geotextile has more functional time before failure than polyester geotextile. Hence should be utilized for design based on serviceability limit state

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