# Shear strength of (composite) geomembrane-soil interfaces

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ABSTRACT: In this study, a series of direct shear tests were conducted on two types of geomembrane-soil interfaces. Both textured and composite geomembranes were used to examine the shear strength. The strain softening behavior can be observed during shearing. Based on the experimental data, the shear strength parameters of (Composite) geomembrane-soil interfaces were calculated by the Mohr-Coulomb criterion. The results show that the textured geomembrane-soil interface exhibits greater shear strength than the composite geomembrane-soil interface and the sandy gravel provides greater shear strength than fine sand.

*Keywords*: Large-scale direct shear apparatus; Shear strength; Geomembrane-soil interface; Textured geomembrane; Composite geomembrane

## 1 INTRODUCTION

Geomembranes (GMs) are widely used in environmental, geotechnical, hydraulic, and transportation activities as barrier layers due to low permeability (Koerner 2012), e.g. landfill basal liners or capping (Touze-Foltz et. al 2009), dams or dikes, reservoirs, tunnel construction, and large-area contiguous liners road construction. The GM barriers can effectively minimize the penetration of liquids in engineered systems. In practical design, GMs or composite GMs are often combined with soils in the impervious liners. For the GM applications mentioned above, interfaces between (composite) GMs and soils should be paid much attention in design. The (composite) GM-soil interface with low shear resistance could become a potential source of failure. Thus, the correct assessment of shear strength of GM interfaces is necessary, and the laboratory tests can provide an effective way to evaluate the shear behavior of GM interfaces.

The general methods currently used to investigate the shear behavior of GM interfaces involve inclined shear test, torsional ring shear test and direct shear test. The inclined shear test can accurately reproduce the real conditions in the lining system for low normal stresses. However, high normal stresses are not easily applied in inclined board test, because a tall sliding block will be needed and a significant overturning moment will be produced. Thus, torsional ring shear test and direct shear test are the suitable choices for the high normal stress cases. Due to the advantages of the torsional ring shear apparatus, such as unlimited continuous shear displacement, constant cross-sectional area during shearing and convenient data acquisition, some torsional ring shear tests were reported in previous studies on the shear behavior of GM interfaces. However, a shear displacement of 40 - 60 cm is typically required to mobilize residual interface shear strength (Stark & Poeppel 1994). By contrast, it is considered that the classic direct shear apparatus provides good peak strength estimation, because the peak strength is mobilized at a small shear displacement (Zabielsk-Adamska 2006).

Over the past few decades, various direct shear tests have been conducted on GM interfaces (Triplett & Fox 2001; Chiu & Fox 2004; Frost et al. 2011; Mariappan et al. 2011; Fox et al. 2014; Vangla & Gali 2016), and smooth GMs are generally used in these tests. Besides the smooth GMs, textured GMs and composite GMs are also effective in controlling the liquid or gas migration in the engineered system (Wu et al. 2014; Thielmann et al. 2016). But the related researches on textured or composite GM interfaces are limited.

In this study, a large-scale direct shear apparatus was used to conduct a series of shear tests on GM-soil interfaces. Textured high-density polyethylene (HDPE) GMs (TGMs) and composite GMs (CGMs) were used to investigate the shear strengths of different GM-soil interfaces, including CGM-fine sand (FS) interface, CGM-FS interface and CGM-sandy gravel (SG) interface. The shear stress versus shear displacement curves were automatically captured during the tests, and the friction angle and adhesion of each interface were calculated by the Mohr-Coulomb criterion.

## 2 TEST APPARATUS AND SCHEME

Figure 1 shows the schematic diagram of a large-scale displacement-controlled direct shear apparatus that was used to simulate the shear behavior of different GM-soil interfaces in the present study. The apparatus comprises loading and control system, shear boxes, and data acquisition system. A 360 mm×360 mm×100 mm upper square box with an inner cylindrical hole of diameter 30 mm is employed. The lower shear box is made of a 360 mm×360 mm×80 mm rigid block. The GM sample is cut into a rectangle of size 480 mm×300 mm. The rectangle sample is then glued onto the lower box and laterally clamped by bolts to avoid sliding. The normal stress is applied to the upper shear box through a pressure rod with a range of 0~100 kN. The shear force is horizontally applied to the lower shear box through a pull-rod. Pressure and displacement transducers are equipped for automatic acquisition of the normal pressure, shear force and shear displacement. The experimental data are recorded by using a data logger. A personal computer is used to control the data logger and to store and manipulate the recorded information.

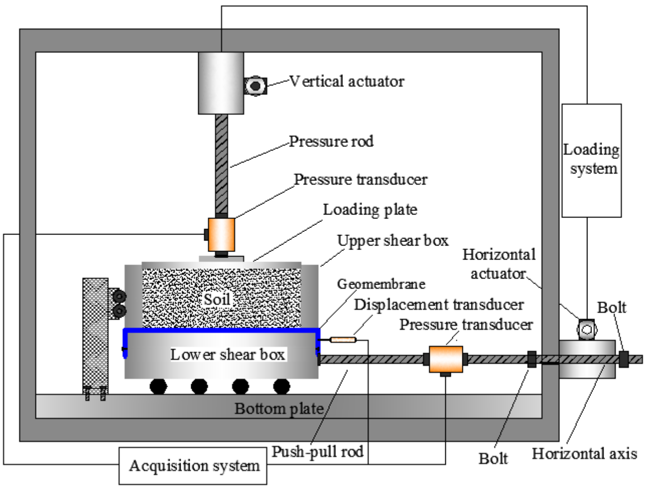


Figure 1. Schematic diagram of the large-scale direct shear apparatus

In this study, a series of direct shear tests on GM-soil interfaces (TGM-FS, CGM-FS and CGM-SG) were carried out under normal stresses of 50, 100 and 200 kPa with virgin samples used for each normal stress. A shear rate of 1 mm/min was set for all shear tests. The shear displacements and shear forces were recorded at 2 s intervals until the shear force did not change significantly.

## 3 TEST MATERIALS

The textured HDPE GMs were used in the tests with a nominal thickness of 2 mm, and a density of 0.94 g/cm$^3$. The composite GMs used in the tests consisted of a 0.8-mm-thick HDPE GMB laminated to a 300 g/m$^2$ needle-punched nonwoven geotextile at both sides. The physical properties of the soils are listed in Table 1.

Table 1. Physical properties of the soils

| Soils | Density (g/cm$^3$) | $d_{10}$ (mm) | $d_{30}$ (mm) | $d_{60}$ (mm) | Coefficients of uniformity $C_u$ | Coefficients of curvature $C_c$ |
|---|---|---|---|---|---|---|
| FS | 1.77 | 0.16 | 0.34 | 0.65 | 4.06 | 1.11 |
| SG | 1.96 | 0.16 | 1.42 | 7.50 | 46.86 | 1.68 |

# 4 TEST RESULTS

## 4.1 *TGM-FS interface*

Figure 2 shows the plots of shear stress versus shear displacement of TGM-FS interfaces. There is an significantly initial rapid increase in shear stress with increasing shear displacement before reaching the peak shear stress. Then the experimental curves show a softening trend, particularly under high normal stress. For higher normal stress, the peak strength gets higher and the corresponding shear displacement is larger. In addition, a higher normal stress also causes a higher residual shear strength.

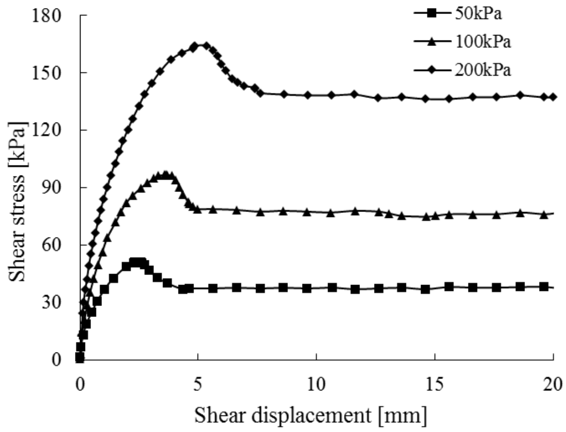


Figure 2. Shear stress versus shear displacement of TGM-FS interface

## 4.2 *CGM-FS interface*

Figure 3 shows the plots of shear stress versus shear displacement of CGM-FS interfaces. A gentle increase in shear stress can be observed with the shear displacement. The peak shear strength typically occurs at a displacement between 5 and 10 mm depending on the magnitude of applied normal stress (50 kPa, 100 kPa, 200 kPa). There is also a softening trend on the experimental curves for CGM-FS interface, with a 7 - 20 % reduction in peak shear stress within a residual shear displacement of approximately 6 - 16 mm.

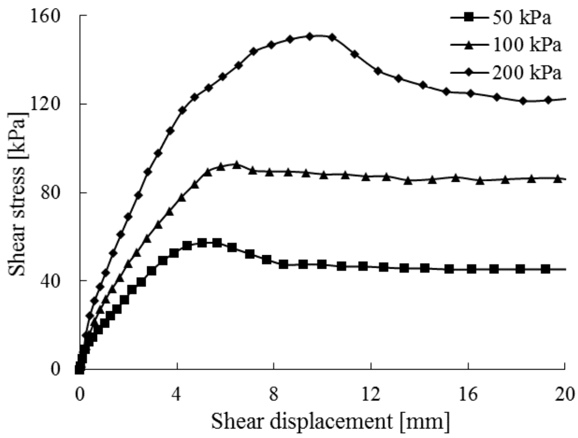


Figure 3. Shear stress versus shear displacement of CGM-FS interface

## 4.3 *CGM-SG interface*

Figure 4 shows the plots of shear stress versus shear displacement of CGM–SG interfaces. It can be observed that the shear stress increases to its peak within a smaller shear displacement compared with CGM-FS interface, after which the softening behavior occurs. The peak shear stresses of the CGM–SG interface are typically 1–10 kPa higher than those of the CGM–FS interface, depending on the normal stress applied (50–200 kPa). However, the reductions of the peak shear stresses of the CGM–SG interface are smaller than those of the CGM–FS interface. In all, the particle shape and gradation of soil exhibit evident influence on the shear behavior of CGM–soil interface.

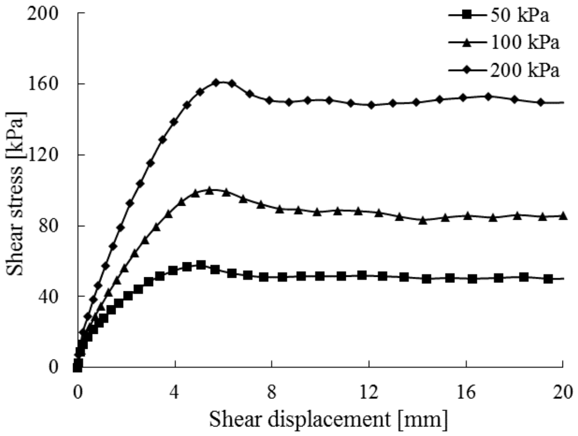


Figure 4. Shear stress versus shear displacement of CGM-SG interface

## 4.4 *Shear strength*

The peak and residual shear strength envelopes of GM-soil interfaces are plotted in Figure 5. The shear strength parameters can be obtained from the envelopes by using the Mohr-Coulomb criterion, which are summarized in Table 2. It is evident that the residual friction angles of each interface are approximate 1 - 5 ° lower than the peak friction angles. Compared with CGM-FS interface and CGM-SG interface, the TGM-FS interface shows the greatest friction angle for both peak and residual shear strengths, but the lowest adhesion.

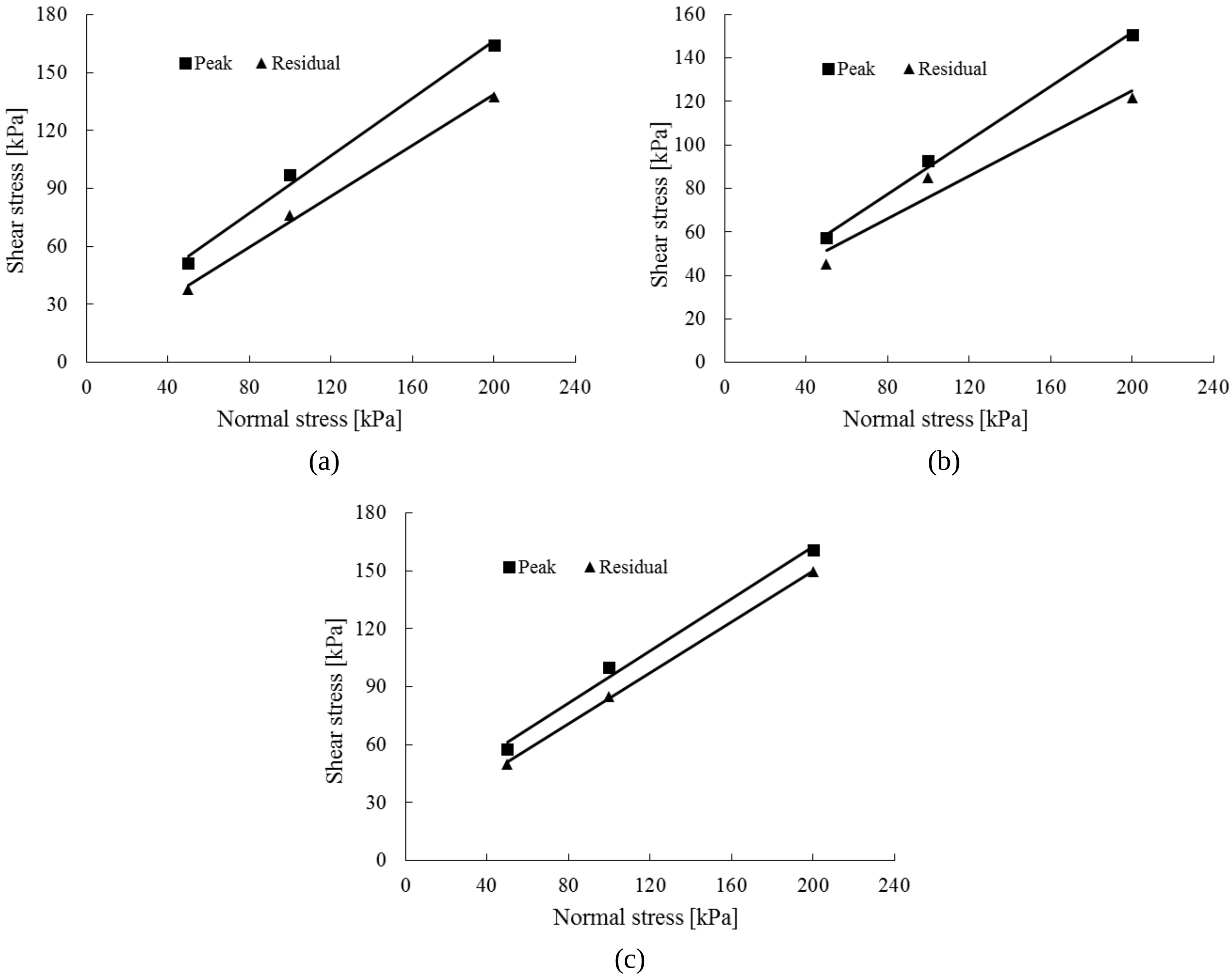


Figure 5. Peak and residual shear stress versus normal stress: (a) TGM-FS interface; (b) CGM-FS interface; (c) CGM-SG interface

Table 2. Monotonic shear strength parameters of GM-soil interfaces

| Interface | Peak shear strength | | | Residual shear strength | | |
|---|---|---|---|---|---|---|
| | Friction angle (° ) | Adhesion (kPa) | Correlation coefficient | Friction angle (° ) | Adhesion (kPa) | Correlation coefficient |
| TGM-FS | 36.58 | 17.65 | 0.9934 | 33.48 | 7.16 | 0.9965 |
| CGM-FS | 31.70 | 28.12 | 0.9973 | 26.08 | 26.92 | 0.9544 |
| CGM-SG | 34.00 | 27.40 | 0.9918 | 33.43 | 17.90 | 0.9995 |

## 5 CONCLUSIONS

In this study, a large-scale shear apparatus was used to conduct a series of shear tests for different types of GM-soil interface. Both TGMs and CGMs were used to reveal the shear behavior of GM-FS and GM-SG interfaces. Based on the test results, the following conclusions can be drawn:

- The GM-soil interfaces exhibits strain softening behavior during the shear test, particularly under high normal stress. For higher normal stress, the peak strength is larger and the corresponding shear displacement is also larger. In addition, a higher normal stress causes a higher residual shear strength. It is evident that the residual friction angle of each interface is 1 - 5 ° lower than the peak friction angle.
- The CGM-SG interface exhibits higher shear stress and greater friction angle than the CGM-FS interface, which reveals that the particle size, shape and gradation of the soils has evident influence on the shear behavior of the GM-soil interface.
- Compared with CGM-soil interface, the TGM-soil interface shows greater friction angle. It is shown that the TGM-soil interface exists greater shear strength, thus, the TGM is a good choice for the stability of a slope with GM barriers. However, considering the protective effect of the geotextile, the CGM is also an alternative as impervious barriers in engineering design and construction.

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