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Influence of wear mechanisms on geosynthetic interface strengths

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ABSTRACT: The results of research that has quantitatively evaluated the amount of wear occurring when geosynthetic materials are placed in contact with soils or other geosynthetic materials are presented. Using measurements of surface roughness obtained before and after shearing, the relative importance of factors such as the geomembrane texturing technique, the geomembrane polymer hardness, the type of geotextile, the physical characteristics of the soil such as particle angularity and the influence of factors such as normal load on wear mechanisms are described. The results also show the importance of considering wear during design. This improved understanding is of significant importance to manufacturers interested in identifying alternative geomembrane texturing procedures and patterns as well as interface strengthening techniques.

1 INTRODUCTION

An interface is formed when two materials are placed adjacent to each other as part of a composite system. The materials may be a continuum or may be discrete. Discrete materials include materials that consist of particles (3D), called “particulate materials”, and materials that consist of fibers (1D). The behavior of the composite system is dependent on the fundamental properties (e.g. hardness, surface roughness) of the materials forming the interface as well as their state (e.g. void ratio, normal stress). Depending on the material properties and state, the interface may evolve under boundary condition changes from a distinct surface to an interfacial zone. Further, depending on the properties of the materials at the interface, the properties of one or both of the materials may be altered during this process of evolution. The term “wear” has been used historically in other fields to describe processes whereby the characteristics of one material at an interface or in an interfacial zone are altered during interactions with the other material or surface (herein generically called “counterface” – the material in contact with the material of interest). For example, removal of the texture on a geomembrane during shearing against a geotextile is a wear process. To date, a variety of wear mechanisms have been identified including geomembrane texture removal, geomembrane surface scarring, geotextile filament breakage, geotextile filament pull-out, and soil clogging of textured surfaces. Given that quantitative measurements of surface roughness have shown it to be a controlling parameter in the measured strength of interfaces (Dove and Frost 1996; Dove et al. 1997; Lee et al. 1998; Frost et al. 1999; Zettler et al. 2000), any changes in roughness due to wear can be expected to have a direct effect on interface strength. These changes can influence both the peak and the residual interface strengths. This paper presents a summary of recent quantitative measurements that show how, through knowledge of the fundamental properties and state of the materials forming an interface, likely wear mechanisms and their significance can be predicted.

2 IMPORTANT PROPERTIES OF COMMON GEOSYNTHETIC INTERFACES

A variety of interfaces are used in applications of geosynthetics in geotechnical engineering. Interfaces involving geomembranes and soils or geomembranes and geotextiles are most common.

2.1 *Geomembrane-soil interfaces*

A geomembrane-soil interface can be described as a continuum-particulate interface. The behavior of such an interface depends on the properties of the continuum and the properties of the particulate material.

The properties of the continuum that are most important with respect to interface behavior are the hardness and surface roughness, as attested to by the variety of geosynthetic products used in practice. For example, the differences in hardness between polyvinyl chloride (PVC) and polyethylene (PE) or even between high density polyethylene (HDPE), low density polyethylene (LDPE) and very low density polyethylene (VLDPE) are well known and how differences in hardness can affect the material behavior is well documented in the literature. Similarly, the variety of texturing techniques that have been used to add surface texture to smooth surfaces (including the co-extrusion, impingement, embossing and lamination processes) attest to the recognized role of surface texture on the performance of the continuum, although this property is only beginning to be quantified on a routine basis in practice.

The properties of the particulate material that are important regarding interface behavior can be identified based on historical experience from the field of soil mechanics. This experience has led to wide recognition of the importance of particle size, shape, mineralogy, and size distribution on the behavior of a particulate material. Finally, the void ratio of the particulate material at the interface and the normal stress have a significant effect on the interface behavior.

2.2 *Geomembrane-geotextile interfaces*

While there may be a tendency to consider geomembrane-geotextile interfaces as continuum-continuum interfaces, this is in many cases not correct. The geomembrane is clearly a continuum and thus the properties noted above for a geomembrane (hardness and roughness) are still the relevant ones to consider in a geomembrane-geotextile system. However, depending on the manufacturing process, the geotextile may possess properties that may make it behave like either a continuum or a discrete material. For example, a monofilament woven geotextile may behave more like a continuum against a geomembrane or other continuum whereas a needle-punched nonwoven geotextile will likely behave more as a discrete material where the fibers are discrete elements that are generally rounded and uniform in diameter. Again, the state (as reflected by the normal stress and density of fibers in the geotextile) can be expected to have a significant effect on the interface behavior.

3 EXAMPLES OF WEAR AT GEOSYNTHETIC INTERFACES

Recent studies have quantified the amount and/or type of wear at common geosynthetic interfaces (e.g. Lee 1998; Zettler 1999; DeJong et al. 2000). Examples of wear at geomembrane-discrete material interfaces are discussed below.

3.1 *Wear of continuum*

For geomembrane-discrete material interfaces, wear of the geomembrane can take the form of either "scarring" of the geomembrane surface or "removal" of texture from the geomembrane surface, depending on the initial surface characteristics. The degree to which either of these phenomena can occur depends on the properties of the geomembrane itself as well as the properties of the counterface material. For example, when compared to quartz soil particles, most polymeric materials have lower hardness values and thus will likely be subject to wear. At the same normal stress, geomembrane wear is likely to be more significant for initially smooth surfaces than for textured surfaces since the presence of the texture tends to cause the particles to "roll" rather than slide or plough into the polymer surface. Similarly, for a given smooth surface, angular particles will tend to plough more readily into the surface than sub-rounded particles. Finally, normal stress level can have a significant effect on the amount of wear that can occur.

As examples of "scarring" wear of smooth geomembrane surfaces, the results of a series of tests where initially smooth HDPE geomembranes were sheared against particles of different angularity and size under a range of normal stresses are presented in Figure 1. The average 2D roughness, R_a, (average orthogonal deviation of the surface from the mean line) of the surface is plotted as a function of the amount of shear displacement. It can be seen that the round glass beads produced the least amount of wear (lowest increase in roughness) whereas the angular blasting sand particles yielded the largest increase in roughness. The influence of particle size can be seen by comparing Figures 1a and 1b. For any particulate material, the effect of increasing normal stress can also be readily seen, particularly above some hardness-dependent critical normal stress level after which ploughing contributes. The actual changes in surface roughness due to wear can also be seen from the post-shear roughness profile measurements taken perpendicular to the shear direction using a stylus profilometer, as shown in Figure 2.

As examples of the "removal" wear of textured geomembrane surfaces, the results of a series of tests where needle-punched nonwoven geotextiles were sheared against slightly and moderately/heavily textured HDPE geomembranes are shown in Figure 3. Note that peak strength, which is governed by microscopic roughness, decreases with wear. However, residual strength is governed by macroscopic roughness and, thus, regardless of the number of retests, the interface shear resistance of the textured membranes will not decrease to that of a smooth membrane for a given counterface material (because macroscopic features are not being removed in the tests). In these tests, new geotextile specimens were sequentially tested against the same geomembrane specimen. The texturing of the slightly textured geomembrane resulted from an impingement process while the texturing of the moderately/heavily textured geomembrane was created using a co-extrusion process. For the impinged surface, it can be seen that some minor change in the shear stress displacement response occurs in successive tests. In contrast, for the co-extruded surface, it can be seen that there is a significant peak in the shear stress-displacement response that is only observed in the initial test of the geomembrane and the response in subsequent tests remains essentially unchanged, reflecting no further significant degradation of the surface. This significant change in surface roughness resulting from the initial testing of the co-extruded geomembrane has been confirmed through the results of 3D roughness, R_s, (actual surface area/projected surface area) measurements conducted after varying numbers of retests (Figure 4). It should be noted that, consistent with Figure 3, each retest results in an additional displacement of 80 mm. The change in roughness is also seen to be directly reflected in the change in peak interface strength (Figure 5).

3.2 *Wear of discrete material*

While the above examples demonstrate wear of geomembranes as they are sheared against discrete materials, it is also of interest to note that wear occurs simultaneously in the counterface discrete materials. In particular, although not conventionally considered from this perspective, the "rearrangement" of discrete

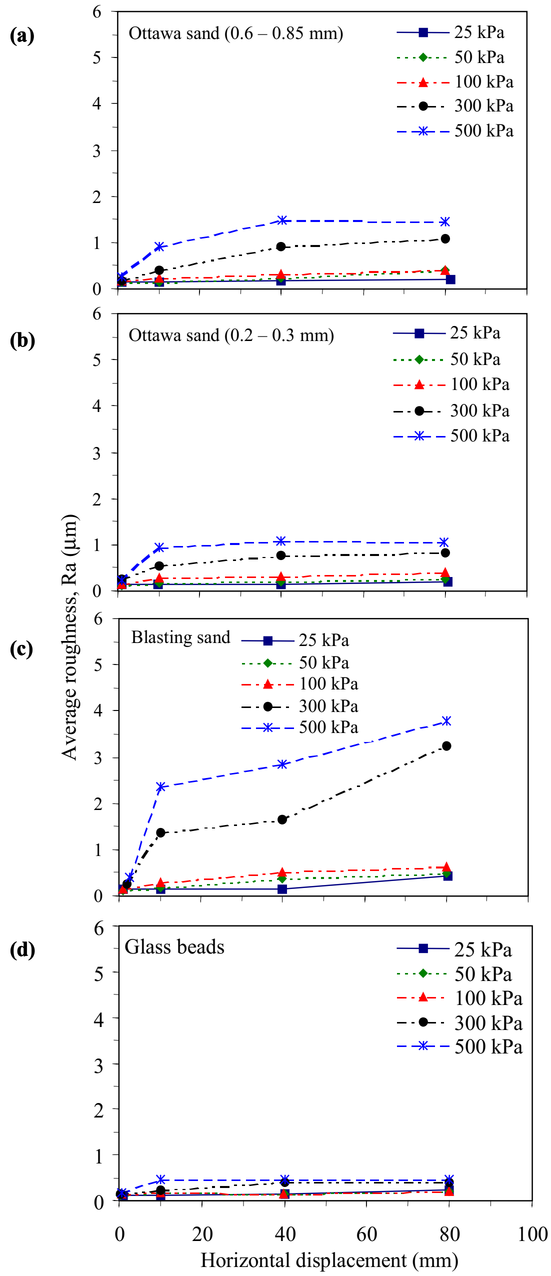

Figure 1. Average surface roughness, Ra, of smooth HDPE geomembranes versus horizontal displacement for several counterface materials: (a) Ottawa sand (0.6 – 0.85 mm); (b) Ottawa sand (0.2 – 0.3 mm); (c) blasting sand; (d) glass beads.

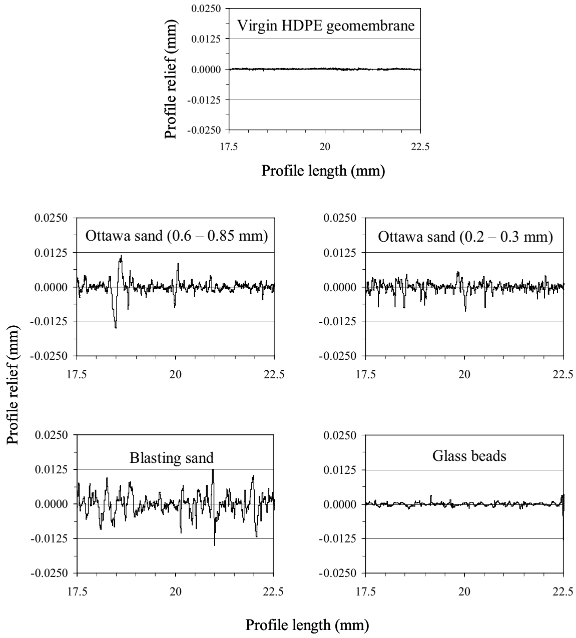

Figure 2. Surface profiles of (a) initially smooth HDPE geomembrane following shearing against (b) Ottawa sand (0.6 – 0.85 mm), (c) Ottawa sand (0.2 – 0.3 mm), (d) blasting sand, and (e) glass beads.

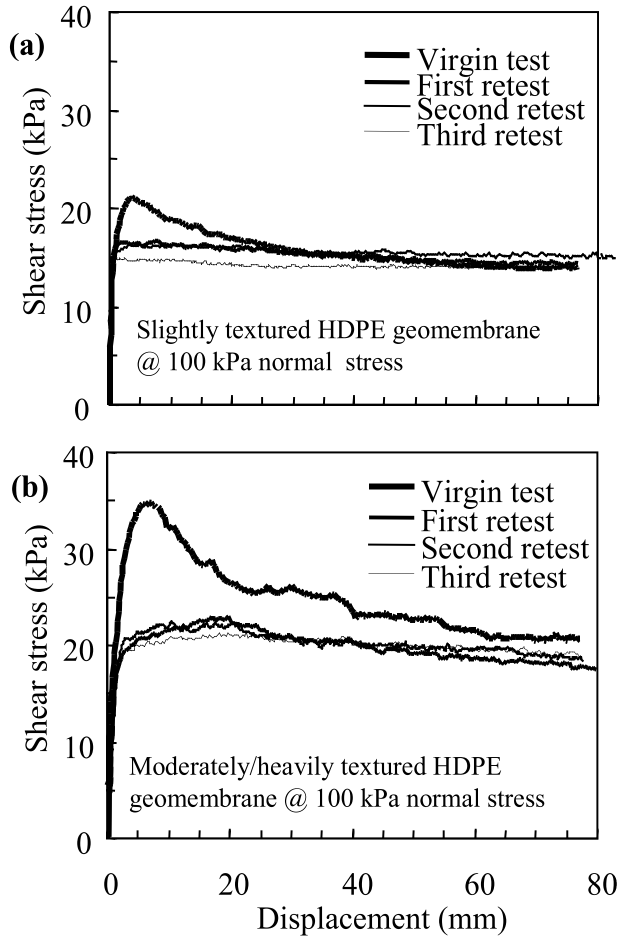

Figure 3. Effect of reshearing geomembrane-geotextile interfaces on the shear stress-displacement curve: (a) slightly textured (GSE Friction Flex) HDPE geomembrane; (b) moderately/heavily textured (Poly-Flex Textured) HDPE geomembrane.

elements in the interface zone is considered herein to also be a manifestation of wear. For example, in a geomembrane-geotextile interface, pulling out and tearing of individual geotextile fibers has often been reported in the literature. This rearrangement of geotextile fibers is clearly consistent with the definition of "wear" whereby the characteristics of one material at an interface or in an interfacial zone are altered during interactions with the counterface material. Similarly, the rearrangement of particles in the interfacial zone of a soil-geomembrane interface is considered herein to be a form of wear of the particulate material (i.e. the soil). This terminology reflects a departure from conventional description of this behavior as microstructure evolution; however, it is considered to be consistent with the definition of "wear" utilized herein.

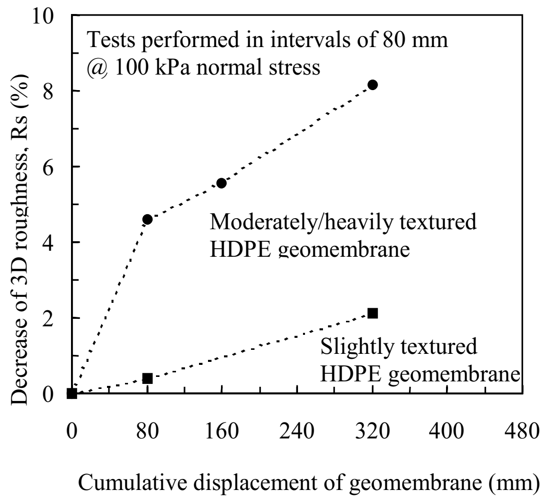

Figure 4. Effect of reshearing the geotextile-geomembrane interface on geomembrane surface roughness.

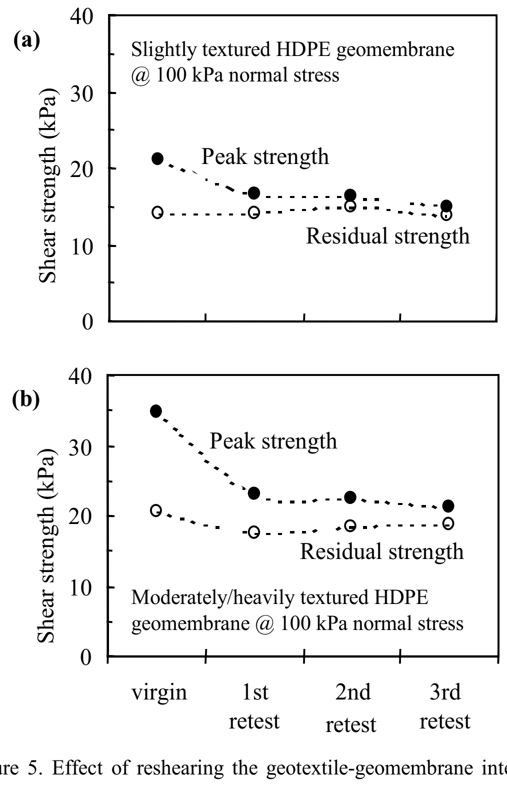

Figure 5. Effect of reshearing the geotextile-geomembrane interface on peak and residual shear strength: (a) slightly textured HDPE geomembrane; (b) moderately/heavily textured HDPE geomembrane.

As examples of this "rearrangement" wear, a series of tests was conducted on interfaces between sands and geomembranes. The results of some of these tests are shown in Figure 6 in terms of void ratio as a function of distance from the interface at different shear displacements (initial/peak/residual). The results shown are for smooth, slightly and moderately/heavily textured HDPE geomembranes sheared against sub-rounded sand under a normal stress of 100 kPa. It can be seen that, for the smooth surface, no significant change in void ratio is observed throughout the height of the specimen. In contrast, the void ratio in an interface zone ranging from 4 to 6 particle diameters increases with increasing shear displacement for both the slightly and moderately/heavily textured geomembranes.

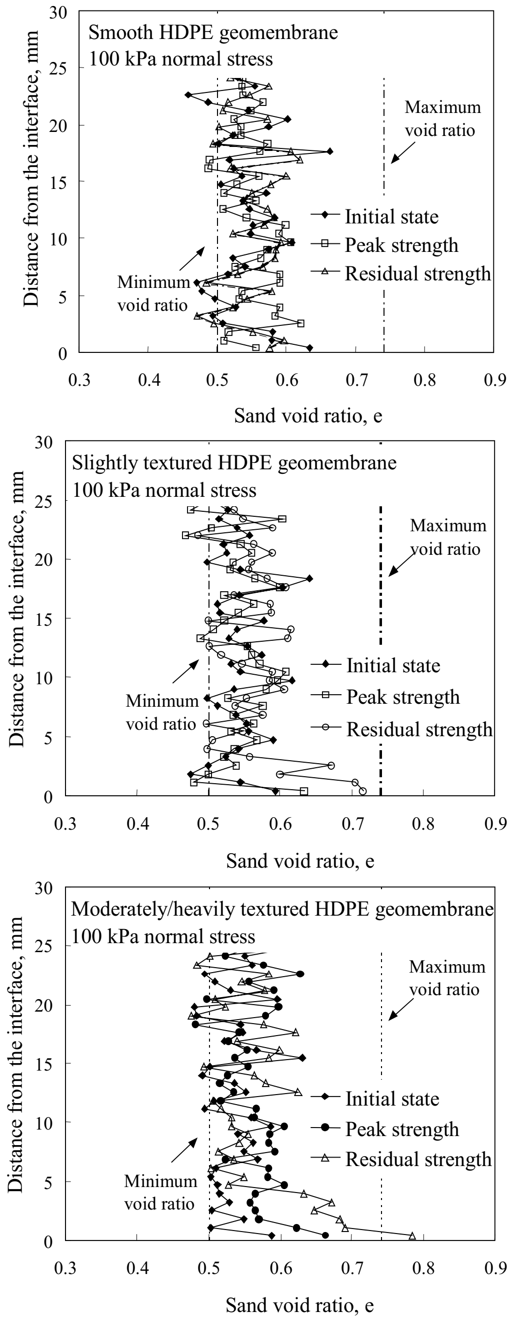

Figure 6. Effect of geomembrane surface roughness on the evolution of sand structure (Ottawa sand, 0.6 – 0.85 mm) in the vicinity of sand-geomembrane interface: (a) smooth geomembrane; (b) slightly textured geomembrane; (c) moderately/heavily textured geomembrane.

4 IMPLICATIONS OF WEAR ON INTERFACE STRENGTH

The above examples have illustrated that wear is a phenomenon that routinely occurs at all interfaces. While all the above examples have focused on evaluating "wear" as a result of a controlled interface strength test, wear can also readily occur during construction before the interface is subjected to normal operating conditions. As such, the potential for, and consequences of, wear should be carefully considered in selecting design properties from laboratory tests. For example, consider the case of an interface between a geomembrane and a geotextile. If, in placing the geotextile on top of the geomembrane during construction, relative displacement occurs between the two materials which causes "wear" of the geomembrane, then the shear stress response under normal operating conditions may not have the peak observed in the virgin test and rather may have a significantly lower value. Similarly, consider the case of an interface between a geomembrane and a soil. If, in placing the geomembrane during construction, relative displacement occurs between the soil and the geomembrane, the state of the material in the interface zone may be significantly different than what is assumed in selecting a design interface strength value.

5 ACKNOWLEDGMENTS

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