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# Using structured geomembranes in final solid-waste landfill closure designs

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## Introduction

Slope failures on final cover systems for solid-waste landfills have been well-documented during the past 20 years with many failures of note within the past three years. Sliding failures have occurred despite known geotechnical reasons for failures and known design methods to avoid slope failures. Many of these failures occur at interfaces with the geosynthetics—most notably at the geomembrane/geotextile interface or geomembrane/soil interface.

Early failures in the 1980s prompted manufacturers to develop and provide an alternative geomembrane with a "textured" surface that increases frictional characteristics and thus increases the factor of safety against sliding failures. However, the most common type of "texturing" manufactured by the blown-film coextrusion process (HDPE and LLDPE) has proven less than acceptable in both surface frictional values and quality of sheet (inconsistency in asperity height, textured surface, and cross-roll friction values). Deficiencies in quality and lower-than-expected asperity height have led to recent slope failures (Sieracke, 2005).

Structured or embossed HDPE and LLDPE geomembranes have been available to the civil engineering community and landfill owners and designers for more than 10 years. Their use in final closure designs has been steadily increasing, especially during the past five years, as owners and designers discover and demand the consistently high quality textured and/or structured characteristics of this type of geomembrane due to the unique manufacturing process that incorporates flat-die extrusion and embossed calendars.

This paper will focus on the structured or embossed geomembrane concept and manufacturing process, as well as presenting comparative properties for consideration in design.

## Surface texturing methods for HDPE and LLDPE

The following paragraphs will briefly describe and discuss the two primary surface texture methods in use currently in North America. Other methods such as surface impingement are available mostly outside of North America and will not be discussed in this paper.

**Figure 1** | Flat-die calendaring manufacture (smooth-sheet production)

**Figure 2** | Flat-die molded textured surface (surface-friction profile)

### Structured (embossed) geomembrane texture

During the flat-die manufacturing process for geomembranes, a hot extruded polymer sheet is run between two counter-rotating hot embossing rollers that contain uniform structural die shapes to form a molded or "embossed" structured or textured surface that is

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an integral part of the sheet without affecting the core thickness. This method has been in use for more than 20 years and was designed to overcome problems of non-uniformity, variable area coverage, variable peaks and valleys, variable thickness, and reduction in mechanical properties that are commonly found with the coextrusion process.

**Figure 1** is a photo illustrating the production method, and **Figures 2** and **3** provide examples of the surface texture generated by the flat-die molded surface manufacturing process. A major advantage of structuring is the ability to create very different surface textures on the upper and lower geomembrane sheet surfaces, thus customizing the specific application (i.e., drainage on top and aggressive friction surface on the bottom).

### Coextrusion geomembrane texture

During the blown-film coextrusion process, molten polymer is extruded in two or three layers through concentric ring dies that are up to 10m (32.8 ft.) in circumference. The outer and inner dies are used to produce layers that can be "textured" or roughened by introducing and allowing nitrogen gas to escape. The texture is formed by the shearing action of the extruder breaking bubbles formed by the cooling of the blowing agent (nitrogen gas) as it expands. This process is known to be highly variable from manufacturer to manufacturer and even within a single roll or across a roll width.

Although the texture cannot be separated or peeled off, the critical mechanical characteristics of the sheet (i.e., tensile stress, strain, tear, and multiaxial response) are substantially reduced due to the introduction of peaks and valleys or surface imperfections that are not found on a smooth sheet. Additionally, non-uniformity of core thickness and even the method used to determine thickness has been questionable and is often a debate in CQA acceptance testing.

**Figure 3** | Flat-die molded structured surface (drain-surface profile)

**Figure 4** | Coextruded surface texture (blown-film process)

**Figures 4** (above) and **5** (p. 14) provide examples of the surface texture generated by the process.

## Comparative properties for design considerations

In addition to the noted differences in surface texturing methods and noted inconsistencies from roll to roll or within rolls on coextruded textured geomembranes as discussed above, the following considerations should be examined during design and ultimate selection of a textured geomembrane.

### Potential for mechanical properties reduction

Reduced mechanical properties of a required sheet thickness due to a texturing process such as coextrusion must be considered, especially for the long term where increasing stresses due to subsidence or localized settlements will occur and affect the out-of-plane (multiaxial) response as well as seam strengths under stress.

Reduced tensile strength and strain to rupture under load will also occur due to increased susceptibility to environmental stress cracking again due to the introduction of notches or imperfections caused by the coextrusion process. Using the flat-die extrusion process, the geomembrane mechanical tensile, elongation and other properties are closer to the values of smooth sheet and do not change from roll to roll as imperfections or thickness variations are not introduced during manufacture.

### Interaction at the shear surface

Depending on the project design requirements (i.e., steep slopes, seismic response, construction, and service loading) the peak and large displacement (post-peak) interface strengths must be taken into consideration. For example, according to Stark and Richardson (2000) and Richardson and Theil (2001), coextruded textured geo-

**Figure 5** | Coextruded surface texture (blown-film process)

membranes exhibit large post-peak strength loss against geotextiles due to geotextile fiber tearing, pullout, and shear orientation.

In addition to geotextile fiber/texture interaction, the texture itself may comb (lay over) causing greatly reduced post peak shear strength (Stark and Richardson, 2000). But embossed surface textures exhibit higher interface shear strength and lower post-peak strength loss at lower normal stresses commonly found in landfill closure designs.

### Constructability with geotextile surfaces

Some designs require the field placement of a textured geomembrane directly on a geosynthetic clay liner (GCL) or placement of a geonet composite or geotextile directly over the textured geomembrane surface. This requires interfacing a nonwoven geotextile with the textured surface. The "Velcro® effect" or "hook-and-loop" adhesion to a coextruded textured surface is often problematic during field placement and requires very careful positioning or the use of a slip sheet.

Embossed geomembrane surfaces, on the other hand, allow positioning of geotextiles and geocomposites without major difficulty. Quantifying of the "hook-and-loop" phenomenon has been the subject of extensive testing and, in particular, testing the effects on interface shear and the textured surface during shear (Hebeler, G. L., et.al., 2005; Giroud, J. P., 2004; Frost, J. D., et.al., 2002).

Geomembranes manufactured with textured surfaces by embossing provide consistent uniform quality texture that will supply the requisite interface shear strength without the detrimental effects of the coextrusion-blown film manufacturing process. Additionally, as regards CQA field testing and laboratory conformance testing, structured or embossed textured geomembranes will provide a consistent value from roll to roll and across the roll width, thus providing requisite design reliability.

This is not the case for coextruded, blown-film, textured geomembranes where "the consistency of the texturing both across the roll and roll to roll should be a concern to the engineering community … What good is direct shear testing if the material provided is not consistent with respect to texturing?" (Sieracke, 2005).

**Table 1** is a summary of several design considerations that should be addressed when selecting a textured geomembrane to enhance slope stability factors of safety.

## Quality measurements

To properly determine the quality and specification conformance of a blown film coextruded texture, multiple locations of discrete measurements must be made using two mechanical test methods, namely

ASTM D 5994 "Test Method for Measuring the Core Thickness of a Textured Geomembrane" and GRI Test Method GM 12 "Asperity Measurement of Textured Geomembranes Using a Depth Gage."

Due to the non-uniform surface, many discrete locations across a full roll width must be tested and averaged with maximum and minimum values. The testing technician tries to obtain the lowest core thickness and the highest asperity height by adjusting measurement locations primarily based on observation. "Both methods have proven to be problematic and have led to numerous conflicts between manufacturer and specifier" (G.R. Koerner and R.M. Koerner, 2005).

Alternative methods to determine these elusive properties have been the subject of several studies and papers (G.R. Koerner and R.M. Koerner, 2005; Yesiller, N.,2005). Structured or embossed geomembrane surfaces (textures), on the other hand, are consistent in both core thickness and asperity height due to the manufacturing process. Thus, multiple measurements to determine average or minimum values are not necessary in QC and CQA testing for structured geomembranes.

### Large-scale, direct-shear performance testing

The interface strength of contact surfaces and in particular interface frictional strength must be determined for the geomembrane/geotextile and geomembrane/soil combinations using project specific geosynthetics, site specific soils materials, expected loading conditions, moisture/density conditions, etc. Mostly, these surface friction determinations are made by experienced personnel in an accredited geosynthetics laboratory using a large-scale, direct-shear box in general accordance with ASTM D 5321 "Standard Test Method for Determining the Coefficient of Soil and Geosynthetic or Geosynthetic and Geosynthetic Friction by the Direct Shear Method" (ASTM, 2006).

This testing has become an essential part of the design process as well as CQA programs that qualify materials for construction. The surface texture consistency is extremely important in this regard and must not change significantly within a roll or from roll to roll. In fact, this has been problematic for coextruded textures that may be tested only once on a sample from

| Design Consideration | Coextruded | Embossed |
|---|---|---|
| Consistent Thickness (cross roll) | No | Yes |
| Consistent Texture (cross roll) | No | Yes |
| Consistent Asperity Heights | No | Yes |
| Asperity Heights >15 mil | No | Yes |
| Consistent Shear Testing (cross roll) | No | Yes |
| Effect on Multiaxial Stress-Strain (Settlement/Subsistence) | Yes | No |
| Texture Combing during Shear | Yes | No |
| Post Peak Reduction in Shear Strength | Yes | Yes |
| Easily Placed with Geotextile Surfaces | No | Yes |
| Increased QC and CQA Costs | Yes | No |

**Table 1** | Summary of Comparative Properties for Design Considerations

| Cap Loading Conditions—ASTM D 5321 | | | | | |
|---|---|---|---|---|---|
| **Material** | **Peak** | **Adhesion** | **LD** | **Adhesion** | **Efficiency** |
| Coarse Sand | 34° | 65 psf | 32° | 15 psf | 92% |
| Lean Clay | 37° | 110 psf | 32° | 30 psf | 97% |
| Silty Sand | 32° | 55 psf | 28° | 10 psf | 100% |
| NW GT | 32° | 80 psf | 17° | 80 psf | NA |
| Notes: 0LD = Large Displacement; NW GT = Nonwoven Geotextile on Geonet Composite | | | | | |
| Cap Loading = 250, 500, 1000 psf; Saturated Conditions | | | | | |

**Table 2** | Representative Interface Shear Values—Embossed Texture

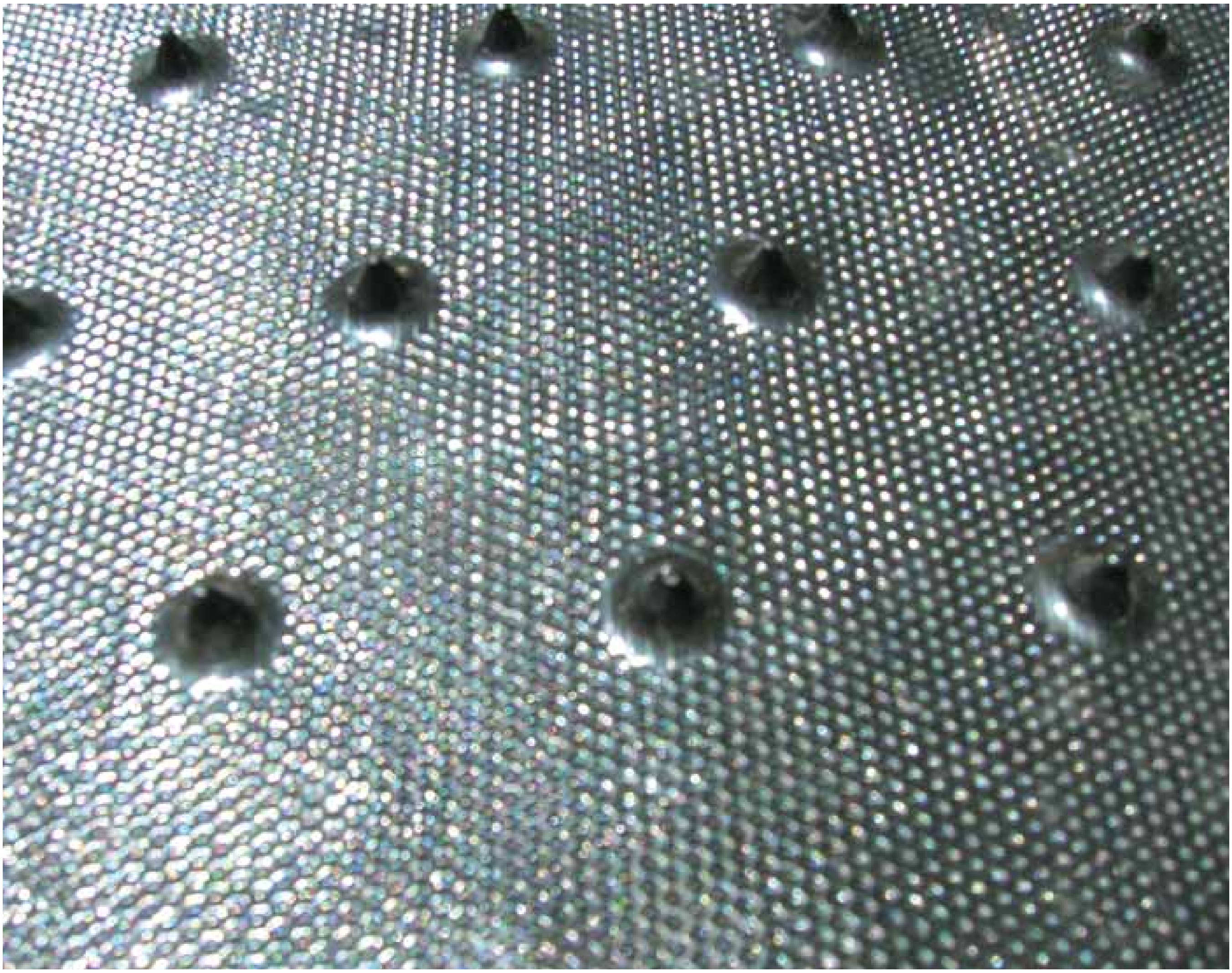

**Figure 6** | Bottom embossed structured or spike surface

the manufacturer vs. what is actually installed in the field and has led to failures due to lower than expected shear strength. If the textured surface of the material actually received in the field is questionable, it is recommended that performance tests be carried out on roll goods that are received on-site to verify requisite interface shear properties.

**Asperity height**

Additional to the requirement for a consistent textured surface, the minimum value of asperity height must be considered (assuming it can be accurately measured). Current specification requirements call for a minimum of 10 mils and reflects GRI Standard GM 13 and 17. However, 10 mils may be considered insufficient for many applications and should be increased to a minimum of at least 15 mils to compensate for known lower values that will be encountered in the coextruded manufacturing process. Both coextruded and structured geomembranes can meet the 15-mil minimum.

## Types of structured/ embossed textures

There are generally three types of structured surfaces available to the design engineer for MSW closure applications:

- General slope applications against soils and geotextiles—25-mil asperity height
- Aggressive slope applications with integral drainage—175-mil asperity height

For general slope applications on slopes of 3H:1V or less, the embossed textured material (refer to previous in **Figure 2**). provides consistent interface shear values against a variety of soil types. **Table 2** illustrates the interface shear values that can be expected with various soil types as well as a nonwoven geotextile. As with all slope designs, large scale performance testing is encouraged using site specific soils and moisture/loading parameters. Aggressive or steeper slope applications are possible with the structured spike (bottom) surface as shown in **Figure 6**.

**Integral top surface drainage**

Structured geomembranes are also manufactured to provide an integral top surface drainage by incorporating a 145-mil stud profile. The top surface of the stud profile is overlain with

| 8 oz/sy Nonwoven Geotextile over 145-mil Drain Stud Profile | | | |
|---|---|---|---|
| Normal Load (psf) | Gradient (i) | Transmissivity ($m^2/s$) | Flow Rate (gpm) |
| 250 | 0.25 | 1.19E-03 | 1.44 |
| 250 | 0.33 | 1.11E-03 | 1.77 |
| 250 | 0.50 | 9.77E-04 | 2.36 |

**Table 3** | 100 Hour Transmissivity Test Results

a nonwoven geotextile for retention of drainage soil placed on top of the structure. Under normal load, the geotextile will intrude into the drain space as with geonet composites. The transmissivity of the drain layer is similar to geonet composites under cap loading conditions without the requirement for a geonet composite resulting in substantial cost savings per acre.

Additionally, the potential for lower than designed interface shear values of a geonet composite against a textured surface is eliminated. The geotextile, once embedded into the stud profile, provides for excellent interface shear values against overlying soil with efficiencies greater than 95%. **Figure 7** shows a typical structured geomembrane stud profile placed on a cap prior to geotextile and soil cover placement.

Based on project specific laboratory conformance testing incorporating site soils, transmissivity values of the drain stud profile with a nonwoven geotextile and soil/cap loading conditions range from 1.1E-03 to 3.6E-03$m^2$/s at a gradient of 0.33. **Table 3** illustrates transmissivity test values for a cap loading condition after 100 hours testing under load. The nonwoven geotextile initially intrudes into the drain structure during increasing normal load similar to geonet composites.

## Summary

Structured or embossed HDPE and LLDPE geomembranes are not new to the geosynthetics industry and design engineers and, in fact, have been used in a variety of civil engineering applications for more than 10 years. Their use in MSW closure applications has been steadily increasing during the past 5 years. The advantages of this type of textured or structured geomembrane are many, including:

- Integral texture or structure embossed within the sheet
- Customized texture or structure top and/or bottom sheet surfaces
- Consistent texture, structure and core thickness from roll to roll or within a roll
- Consistent and reliable interface shear properties from roll to roll or within a roll
- Consistent mechanical and multiaxial strain properties
- Steep slope applications potential (aggressive spike profile surface)
- Integral surface drainage potential (drain stud profile surface)
- Cost-effective in QCA cost reductions (both field and laboratory)
- Cost-effective alternative to geonet composite placed over a textured sheet (structured drain profile)

It must be emphasized that project specific specifications and performance testing regarding required performance characteristics for a textured geomembrane is the design engineer's responsibility. The design engineer must be aware of the differences in the available types of textured materials and develop design specifications and CQA plans that will ultimately satisfy project requirements regardless of the material supplied.

**Figure 7** | Structured drain profile on a slope prior to geotextile/cover soils placement

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