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The Use of Continuous Filament Geotextiles as Puncture Protection Opposed to Staple Fibre for the Protection of Geomembranes

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Abstract

Geotextiles, collectively known as geosynthetics, are commonly used in the industry as a cushioning barrier between geosynthetic lining systems such as dams or lining cells in landfills. The geomembranes must be cushioned and protected from adjacent materials such as crushed stone drainage layers. Due to the angularity and hardness, these present a risk of damage to the liner, both physical and strain-induced stress cracking. These physical properties of natural materials can lead to long-term damage to the geomembrane, and in-turn increase leakage from waste containment facilities. The result of this is catastrophic. The protection geotextile plays an important role in absorbing these localized stresses and ensuring that the integrity of the liner is kept. The specifications for the protection geotextiles are generally based on the Geosynthetic Research Institute's GRI GT12 document and focus on the mass of the geotextile rather than other mechanical properties such as CBR. Various samples of continuous filament and staple fibre geotextiles equivalent to those required by the GRI GR12 document were sent to an independent laboratory for testing. The following paper will detail the tests done, as well as analyse and compare the test results for each geotextile and highlight the need for another property to be considered besides mass alone.

Keywords: *Geosynthetics Properties and Testing, Liner protection geotextile, GRI GT12, ISO Test Method, ASTM test method, Continuous Filament, Staple Fibre.*

1. Introduction

Geotextiles, collectively known as geosynthetics, are commonly used in the industry as a cushioning barrier between geosynthetic lining systems such as lining cells in landfills. The geomembranes must be cushioned and protected from adjacent materials such as crushed stone drainage layers. Physical and strain-induced cracking can be caused by the angularity and hardness of these drainage layers, presenting both physical damage and strain-induced cracking to the liner. These physical properties of natural materials can lead to long-term damage to the geomembrane, and in-turn increase the leakage of harmful substances from waste containment facilities into the environment. The result of this is catastrophic. The protection geotextile plays an important role in absorbing these localized stresses and ensuring that the integrity of the liner is kept. The specifications for the protection of geotextiles are generally based on the Geosynthetic Research Institute's GRI GT12 document and refer to non-woven geotextiles in general. When designing a protection geotextile, it is crucial to consider the factors that ensure its effectiveness and longevity. Early attempts were made to assess cushion effectiveness based on the mass of geotextiles. However, numerous studies have proven that the type of polymer/fibre type/fibre blend and manufacturing method can significantly impact the performance despite having the same fabric mass. While mass has traditionally been regarded as an important factor, it is worth exploring that perhaps it is not as crucial in the design process.

GRI has developed standard specifications for protection geotextiles, and design engineers have taken the liberty to alter these values after conducting laboratory tests to keep up with the latest technology and manufacturing capabilities. However, in the past few years, it has once again become common to see other important mechanical properties being neglected, and the specification of mass prevailing. Various samples of continuous filament and staple fibre geotextiles equivalent to those required by the GRI GT12 document have been tested at an independent laboratory. The following paper will detail the tests done, as well as analyze and compare the test results for each geotextile and highlight the difference between a continuous filament non-woven geotextile, and a staple fibre non-woven geotextile, as well as how mass is irrelevant to the outcome.

2. Why use a protection geotextile

Leachate is defined as any contaminated liquid that is generated from water percolating through a solid waste disposal site, accumulating contaminants, and moving into subsurface areas. The composition of the leachate varies widely based on the age of the landfill as well as the type of waste that it contains. Many factors influence the design of a new landfill, one of them being the type of waste being disposed of, and the leachate it will create. Figure 1 below is an example of a typical layout of a cell lining system:

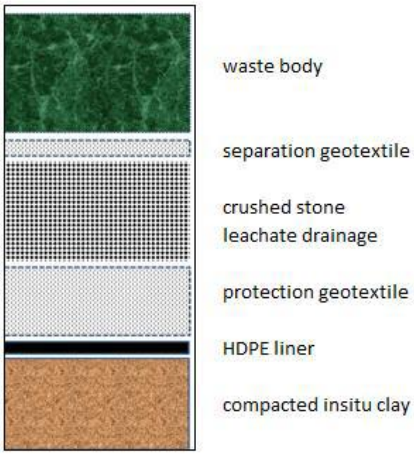

Figure 1. Typical layout of a cell lining system.

The lining systems in landfill cells are crucial in the collection and diversion of the leachate to a collection sump where it can be safely removed and treated. However, the liner is subject to physical damage caused by stresses and strains that occur during the installation and operation of the landfill, especially due to the stone aggregate directly above it. Protection geotextiles serve as a cushioning layer between these liners and aggregates to absorb and distribute the load more evenly across the liner, reducing the risk of localized damage, which in turn extends the lifespan of the landfill. These materials possess excellent resistance to physical, chemical, and biological degradation, making them ideal for long-term use in various challenging environments.

The geotextiles are engineered with a combination of mechanical properties such as tensile strength, puncture resistance, and durability to provide efficient protection to the infrastructure. They effectively distribute loads, mitigating mechanical stresses that can lead to soil erosion, subsidence, or differential settlement. It is also proposed that the protection performance of a needle-punched non-woven geotextile is strongly related to inter-fibre friction as depicted in figure 2 below:

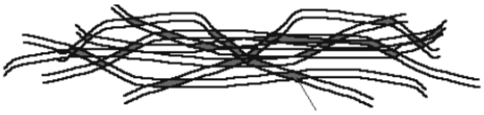

Figure 2 – Fibre contact area

Additionally, protection geotextiles act as a separation layer between the waste and the HDPE liners. They prevent direct contact between the liners and the leachate, minimizing the potential degradation of the liner material due to chemical or biological factors present in the leachate. This separation also helps to maintain the stability and effectiveness of the liner system. When it comes to landfill liner protection, different types of geotextiles can be used, however, continuous filament nonwoven geotextiles and staple fibre nonwoven geotextiles are most common. While both types of geotextiles offer certain advantages and disadvantages, their different characters make them better suited for different applications.

2.1. Continuous filament nonwoven geotextiles (CFNs)

CFNs are made from long, continuous fibres that are either thermally bonded or needle punched together to form a strong, durable geotextile. CFNs are typically heavier and thicker than SFNs, which makes them more resistant to puncture and tears, however, advances in technology allow the CFNs to be lighter while still providing high puncture resistance.

One of the main advantages of CFNs as landfill protection is their high tensile strength, this allows them to resist stresses and strains that occur during installation and operation, such as stretching, tearing, and puncturing. They also offer excellent puncture resistance and a cushioning effect to protect liners and soil. Additionally, they have excellent filtration properties, allowing them to prevent clogging and migration of fine particles while still allowing water and gases to flow through to maintain the integrity of the landfill liner.

2.2. Staple fibre nonwoven geotextiles (SFNs)

In contrast to CFNs, SFNs are made from shorter, discontinuous fibres that are mechanically interlocked to form a web-like structure. They also offer good filtration properties, although they may not be as effective as CFNs at preventing the migration of fine particles.

One of the main advantages of SFNs as landfill protection is their cost-effectiveness. Compared to CFNs, SFNs are generally less expensive to produce and install, making them a more attractive option for projects with tight budgets.

However, SFNs may not offer the same level of filtration as CFNs, which can compromise the integrity of the landfill liner. They also may not be as durable as CFNs, which can make them more vulnerable to damage during installation and operation, as will be evident with the following tests performed.

3. Testing

The below information refers to testing done at an independent TRI laboratory on various nonwoven protection geotextiles when subjected to 260 & 500kPa confining pressure. Testing was carried out using ASTM D5514 – Large Scale Hydrostatic Puncture Testing of Geosynthetics apparatus modified to include the use of a fixed stone profile and 3D laser surface profilometry (LSP), while the strain analysis was determined using the Hornsey & Wishaw method. These test routines allow the measurement of strain across the whole surface area of the geomembrane and provide a very accurate assessment of the maximum strain developed. The maximum strain value is crucial in evaluating the long-term stress crack.

3.1. Test Parameters

3.1.1. Drainage gravel

Angular crushed stone

3.1.2. Protection Geotextile

1. ~1 500g/m² continuous filament nonwoven needle punched polyester geotextile
2. ~1 500g/m² staple fibre polyester nonwoven geotextile
3. ~1 000g/m² continuous filament nonwoven needle punched polyester geotextile
4. ~1 000g/m² staple fibre polyester nonwoven geotextile
5. ~800g/m² continuous filament nonwoven needle punched polyester geotextile

3.1.3. Geomembrane

1.5mm-thick smooth HDPE geomembrane

3.1.4. Apparatus

The assembled combination of the products that was sent was tested using a Large-Scale Hydrostatic Puncture Testing Geosynthetics apparatus in the inverted profile and subjected to pressures up to 500kPa (Figure 3).

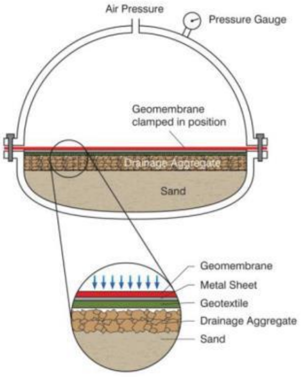

Figure 3. Large Scale Hydrostatic Geosynthetics
Puncture Testing Apparatus – inverted profile

In this test, a 0,3mm aluminum sheet is placed between the geotextile and the geomembrane and then pressure is applied. The aluminum sheet is then removed and scanned with a laser device to analyze the strain distribution and determine the maximum strain. The testing followed the ASTM D5514-06 test procedure which was modified to include the use of a fixed stone profile and uniform pneumatic load application. To ensure repeatable loading onto the liner, fixed stone profiles (Figure 4) were created using fibre-reinforced resin to hold the drainage stone in a rigid arrangement yet provide a natural stone surface pattern and texture similar to that of stone as placed on site.

Figure 4. Stone Profile in Test Rig.

Figure 5. Protection Geotextile.

Using this approach, different liner and geotextile (Figure 5) combinations were tested against the same stone profile and loading conditions, thus enabling direct comparison of damage, geomembrane strain, and cushioning performance. This test routine allows the measurement of strain across the whole surface area of the geomembrane and provides a very accurate assessment of the maximum strain developed in it. The maximum strain value is crucial in evaluating the long-term stress crack potential of the geomembrane.

4. Results

4.1. 3D Laser scanning images

The images presented below is an example to show the damage of the aluminum sheet (Figure 6) caused by the stone aggregate after either 260 or 500kPa of pressure has been applied, as well as the laser scanning (Figure 7) done on this aluminum sheet to make an accurate determination of the percentage strain that has occurred over the sample within the limits of the testing duration. Another laser scanning (Figure 8) has been added as an example of the strain on the aluminium sheet without any protection geotextile.

Figure 6. Damage to aluminum sheet under 250kPa or 500kPa applied Pressure.

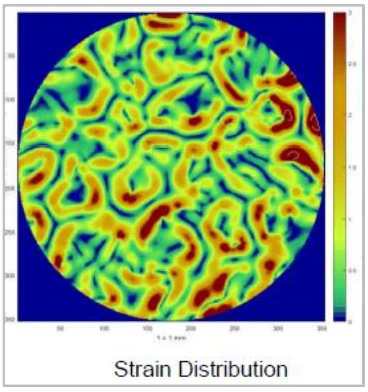

Figure 7. Strain distribution on either CFN's or SFN's under 250kPa or 500kPa Applied Pressure.

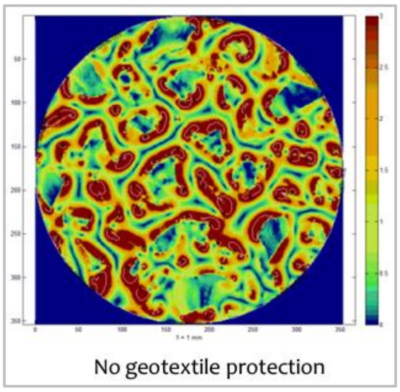

Figure 8. Example of strain distribution on aluminium sheet without protection geotextile.

4.2. Graphs

The relative performance of the geotextile protection layer in conjunction with the stone profile and pressure variances is provided in the below graphs:

* The limit of precision of the scanning equipment used by the laboratory is reached at 0.05% area. The maximum strain value is taken at the intersection of these lines.

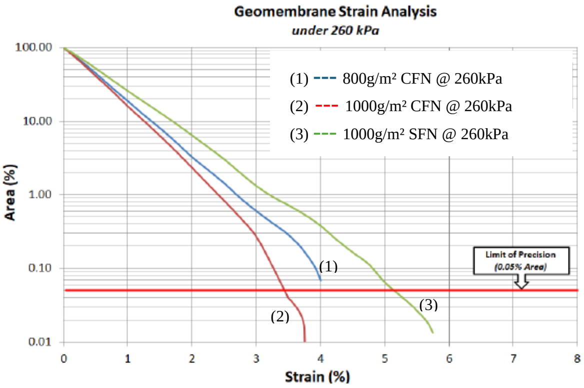

Figure 9. Geomembrane Strain Analysis 1 – 800g/m² CFN, 1000g/m² CFN, 1000g/m² SFN under 260kPa

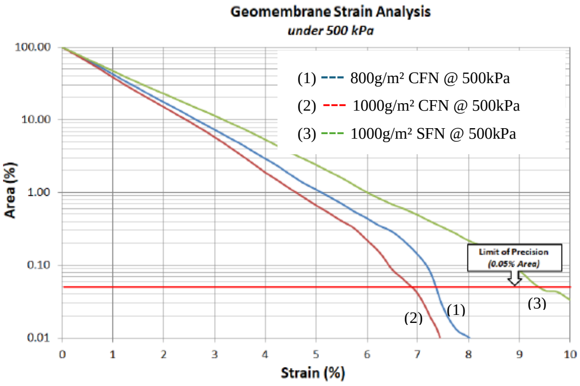

Figure 10. Geomembrane Strain Analysis 2 – 800g/m² CFN, 1000g/m² CFN, 1000g/m² SFN under 500kPa

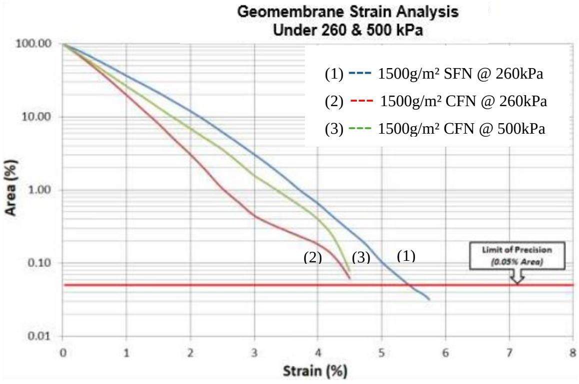

Figure 11. Geomembrane Strain analysis 3 – 1500g/m² CFN under 260kPa & 500kPa, and 1500g/m² SFN under 260kPa

4.3. Findings

The maximum strain recorded at the limit of accuracy of the method was:

1. 260kPa – 1 500 g/m² SFN polyester geotextile– 5.5%
2. 260kPa – 1 500 g/m² CFN polyester geotextile – 4.6%
3. 500kPa – 1 500 g/m² CFN polyester geotextile – 7.75%
4. 260kPa – 1 000/m² CFN polyester geotextile – 3.45%
5. 500kPa – 1 000/m² CFN polyester geotextile – 6.9%
6. 260kPa – 1 000 g/m² SFN polyester geotextile – 5.1%
7. 500kPa – 1 000 g/m² SFN polyester geotextile – 9.5%
8. 260kPa – 800g/m² CFN polyester geotextile – 4.0%
9. 500kPa – 800g/m² CFN polyester geotextile – 7.35%

The strain analysis was done as per the Hornsey & Wishaw method.

4.4. Test results summary

Geotextile type	**Mass (g/m²)**	**Gravel**	**HDPE liner**	**Test setup**	**% Strain**	
					260 kPa	**500 kPa**
Continuous	1500	Angular crushed	1.5mm smooth	inverted	4.6	7.75
Staple fibre	1500				5.5	/
Continuous	1000				3.45	6.9
Staple fibre	1000				5.1	9.5
Continuous	800				4	7.35

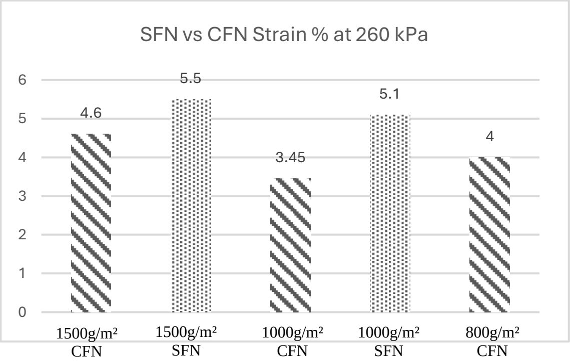

Figure 12. Bar column of CFN vs SFN Strain @ 260 kPa

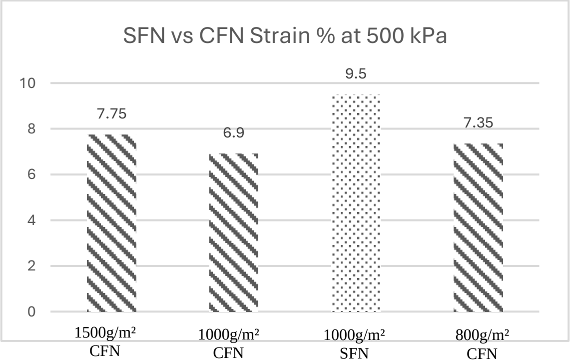

Figure 13. Bar column of CFN vs SFN Strain @ 500 kPa

As shown in Figures 12 and 13, when the strain values of a given mass are compared, it is evident that the continuous filament nonwoven geotextile proved to outperform the staple fibre nonwoven polyester geotextile. Furthermore, the mass required for CFN geotextiles is often lower than staple fibre geotextiles to provide equal or better performance. A 1000g/m² SFN under 260kPa in this case would result in 5.1% max strain imposed on the geomembrane, compared to 1000g/m² CFN at 3.45% strain value.

This can be looked at in another way, if the maximum strain on the geomembrane was to be limited to 4% @ 260kPa, then a CFN at ~1000g/m² could be utilized, but to limit the same 4% strain with SFN you will need over 1600g/m². For an average of 500 000m² on a typical landfill site, this equates to an additional cost of R15mil to the client.

Note that the strain allowable in the industry is typically less than 3%, but this Large Scale Hydrostatic Puncture Test greatly exaggerates on-site conditions. The stone profile in the test mould (Figure 5) has not 'settled' the same way the stone would be on site after compaction and vibration from the construction vehicles. Based on further studies done by Peggs et al. it could be argued that the maximum allowable global strain value of 3%, and a limited local strain of 0.25% should be re-evaluated and increased, as these values do not reflect current products and practices.

4.5. Result Analysis

Due to the previous evaluation methods of geomembranes, geotextiles for protection were frequently chosen based on mass as the primary factor. We have learned that the protective effectiveness may differ significantly among different geotextile varieties, depending on the type and size of the aggregate, and specifying by mass has proven erroneous, especially when backed by Protection Efficiency testing. As shown in Figure 10, if the strain values for a given geotextile mass are compared at 1000g/m² under 500kPa, it is apparent that continuous filament, polyester geotextile (6.9% strain) outperforms the staple fibre geotextile (9.5% strain).

It is evident that not all geotextiles are created equally when it comes to cushioning performance, and this becomes very important when specifying these products. It is too often found that mass is used to specify a protection geotextile when it is evident that a geotextile at a lower mass (CFN geotextile) can perform better than one with a higher mass (SFN geotextile). The GRI GT12 guidelines are often used as a benchmark to specify these geotextiles, which include specifications for mass, trapezoidal tear strength, puncture, and grab. CFN geotextiles often outperform these specifications, and the GRI GT12 guidelines seem low as a representation of current geotextiles. Arguably, the best way to specify protection geotextile will be to use previous test results, as well as geotextiles used under the same conditions as a benchmark to specify the intended properties.

5. Conclusion

Continuous filament nonwoven (CFN) polyester geotextile has consistently shown more favorable results than staple fibre nonwoven geotextiles in providing strain attenuation of HDPE geomembranes under angular aggregates.
The resistance of CFN polyester geotextiles to abrasion and piercing, while still retaining a high tensile strength makes this geotextile the preferred protection geotextile above lining membranes. Ease and speed of installation compared to sand protection layers, especially on slopes, is a great advantage.

6. References

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