Interpretation of In-Plane Flow Capacity of Geocomposite Drainage by Tests to ISO 12958 with Soft Foam and ASTM D4716 with Various Natural Backfill Materials.

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ABSTRACT
The in-plane flow capacity of geocomposite drainage products is significantly affected by the boundary conditions of the backfill. This is known to be due to the intrusion of the geotextile surface of the geocomposite into the core of the geocomposite. Test standard ISO 12958 utilises a simulated soil and ASTM D4716 enables a range of actual site materials to be used. The soft foam simulated soil is shown to under estimate the extent of geotextile intrusion caused by a typical cover soil. Core compression is shown to account for 20% of the loss of short term in-plane flow capacity and geotextile intrusion is shown to account for a further 65% loss of short term in-plane flow capacity. The continuing loss of performance with time is discussed.

1. INTRODUCTION

Geocomposite drains consist of a polymer core bonded to a geotextile on one or both sides of the core. There are many forms of polymer core, the most common being geonet (bi-planar or tri-planar), cuspate (single or double) and random fibre (plain or zigzag). The most common polymers for the core are high density polyethylene (HDPE) and polypropylene (PP) whilst high impact polystyrene (HIPS) or nylon (PA) are also used. The function of the core is to support the geotextile whilst at the same time creating a planer void through which water can flow.

ISO 12958 is the International standard for in-plane flow tests of geotextiles and related products such as geocomposite drains. This standard, formulated over many years, was launched in 1997 and revised in 2007.
ASTM D4716 is the American standard for in-plane flow tests of geotextiles and geocomposite drains. This standard was launched in 1995 and last revised in 2008. These test standards are used to conduct the in-plane flow tests that form the basis of the short-term flow performance of gecomposite drains that is published on product datasheets. These in-plane flow tests are most often used to determine the flow in the machine direction (MD) or length of the geocomposite drain. They can equally be used to test the flow in the cross machine direction (CMD) or width of the geocomposite drain. Most geocomposites have markedly different in-plane flow performance in the machine direction (MD) and cross machine direction (CMD).

The tests conducted for this paper are in the machine direction (MD) as this is the primary direction of flow intended by most geocomposite manufacturers. The tests conducted here show short term in-plane flow performance. The tests are conducted with water at 20°C and it should be noted that if comparisons are to be made to the flow through traditional granular drainage layers then water at 10°C is approximately 30% more viscous than water at 20°C and a reduction factor R_T should be applied to the in-plane flow capacity of the geocomposite. The long term flow expected during the design life will be reduced by amount based upon the creep performance of the geocomposite and often this reduction is significant. Reduction factors should also be applied for the potential loss of long term performance due to chemical clogging R_{CC} and biological clogging R_{BC} .

In-plane Flow

The in-plane flow capacity of a geocomposite drain is particularly affected by the confining pressure applied to the drain. The confining pressure is the result of the weight of the backfill material plus any live loads e.g. traffic. This confining pressure acting on the geocomposite will cause two effects:

1) a slight reduction in the thickness of the geocomposite core and consequently a slight reduction of the in-plane flow capacity of the geocomposite

2) Intrusion of the geotextile surface into the core of the geocomposite and this causes a significant reduction of the in-plane flow capacity of the geocomposite.

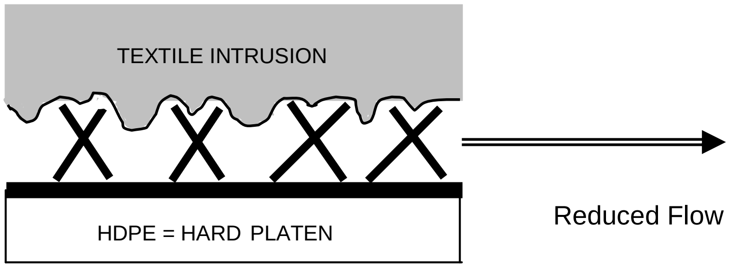

Figure 1. Confining pressure causes textile intrusion into the core of the geocomposite.

The test methods used to assess the in-plane flow capacity of a geocomposite drain must replicate the forces and pressure distribution applied in the real life situation, especially those causing the intrusion of the geotextile into the core of the geocomposite. Often this is achieved by use of a soft foam rubber platen placed in contact with the test specimen and through which the various confining pressures are applied. To replicate a landfill capping which typically consists of cover soil on top of the geocomposite drainage layer above a HDPE geomembrane, the soft foam platen is placed on the top of the specimen and a hard steel platen below. In a previous paper (Bamforth 2008) a landfill capping consisting of cover soil on top of a geocomposite drainage layer above a GCL was modelled with soft platens top and bottom. The object of this paper is to determine whether the soft foam rubber realistically replicates the usual soil and crushed stone backfill used in real life applications. It is worth noting at this point that in-plane flow tests can also be conducted with hard steel rigid platens both sides and that such tests do not simulate any geotextile intrusion and therefore only truly represent the higher in-plane flows achieved by geocomposites in hard boundary conditions such as landfill leak detection layers where there is a HDPE geomembrane both sides or internal drainage of hard rock tunnels.

2. METHOD

Rolls of two different forms of geocomposite drain were obtained from two different European Manufacturers.
The relevant data from the published datasheets are shown below.

Table 1. Published Datasheet Information for apparently broadly similar products

					Mean Short Term (MD) In-Plane Flow (l/m/sec)			
Type of Geocomposite	**Thickness (mm) Mass (g/m²)**	**Test Standard**	**Stated Boundary Conditions**	**Confining Pressure (kPa)**	**HG 1.0**	**HG 0.3**	**HG 0.1**	**HG 0.01**
Single Cuspate 	4.7 570	ISO 12958	SOFT	20 50 100 200	0.95 - 0.75 0.60	- - - -	0.25 - 0.20 0.15	- - - -
Random Fibre Open Zig-Zag 	6.5 660	ISO 12958	HARD	20 50 100 200	1.3 1.2 1.0 -	0.65 0.60 0.55 -	0.33 0.30 0.25 -	- - - -

Both of the above products appear to have broadly similar performance, are at the lower end of each manufacturers range and are typically used for drainage of landfill caps. Samples of each geocomposite were taken and tested by laboratories accredited for the appropriate ISO 12958 and ASTM D4716 in-plane flow test standards. The samples of each geocomposite were tested with hard steel rigid contact surfaces, soft foam rubber contact surface and a range of natural crushed stone and soil backfill materials.

2.1 ISO 12958 Test Method for In-Plane Flow

Each specimen of each geocomposite was placed in the transmissivity test rig. The specimens were 300mm wide and 450mm long. To replicate the real life situation of an HDPE geomembrane, the geocomposite specimen was placed onto a hard lower surface. A soft foam rubber platen and finally a loading plate were placed on top of the specimen. This test method uses a soft foam rubber which has been characterised to the requirements of the standard to represent typical backfill material. Confining pressures of 20, 50, 100, 200kPa were applied in turn whilst water at 20°C was passed through the specimen at hydraulic gradients (HG) of 1.0, 0.3, 0.1 and 0.01. The in-plane flow capacity of each specimen was calculated from a defined volume of water (0.5 litre) collected in a measured time period typically 5 ses – 10 minutes.

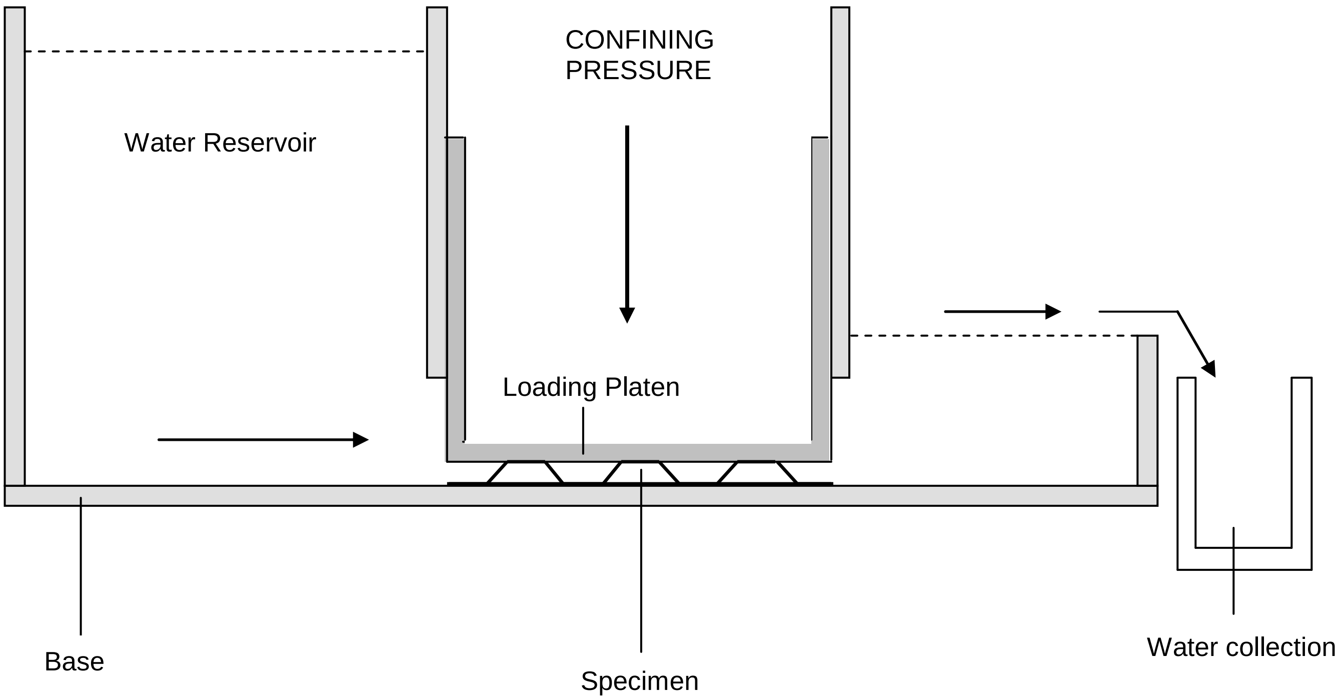

Figure 2. Diagram of the transmissivity rig used in ISO 12958 and ASTM D4716

2.2. ASTM D4716 Test Method for In-Plane Flow

Each specimen of each geocomposite was placed in the transmissivity test rig. The specimens were 305mm wide and 355mm long. To replicate the real life situation of an HDPE geomembrane, the geocomposite specimen was placed onto a hard lower surface. The chosen backfill material was then placed onto the specimen. The loading plate was positioned and a confining pressure of 20kPa was applied and held for 1 hour. Water at 21°C was passed through the specimen at hydraulic gradients (HG) of 1.0, 0.3, 0.1 and 0.01. The in-plane flow capacity of each specimen was calculated from the measured volume of water collected in a defined time period - typically 15 minutes. The accuracy of results is expected to be 20%.

The test was repeated at 50, 100 and 200kPa. Each held for 1 hour.

The backfill materials used were

- Soft Foam Rubber block
- Gravel
- Sand
- Low permeability cover soil

The grading analysis of the gravel, sand and cover soil is shown below. The sand classifies as a silty sand and the soil classifies as a sandy silt.

Table 2. Sieve Analysis of the Sand

Sieve Size (mm)	Percentage Passing (%)
9.5	100.0
4.75	84.7
2.00	41.6
0.85	26.4
0.425	21.4
0.250	19.0
0.100	17.1
0.075	14.9

Table 3. Sieve Analysis of the Soil

Sieve Size (mm)	Percentage Passing (%)
9.5	100.0
4.75	99.6
2.00	99.3
0.85	98.9
0.425	98.4
0.250	94.3
0.100	80.9
0.075	62.8
Hydrometer Analysis	
0.074	61.2
0.005	16.1
0.001	11.0

Table 4. Sieve Analysis of the Gravel

25	95 - 100
13	25 - 60
4.75	0 - 10

3. RESULTS

The results of the in-plane flow tests using ISO 12958 and ASTM D4716 are presented in table 5 and table 6. For both test standards there is a significant difference (approx 20 - 50%) in the in-plane flow results between tests using hard platens both sides and soft foam rubber platen on one side/hard platen on the other side. With hard platens both sides, the in-plane flow performance reduces (approx 20%) with increasing confining pressure and this is a result of the confining pressure causing compression of the core of each geocomposite. With soft foam platen one side, the in-plane flows are lower and reduce more severely (approx 30%) with increasing confining pressure and this is the result of the intrusion of the geotextile surface into the core in addition to the compression of the core. For both geocomposites, the in-plane flow results to ISO 12958 and ASTM D4716 with hard platens are very similar despite the different durations of the tests.

The in-plane flow results to ISO 12958 with soft foam rubber are higher (approx 15%) than the results to ASTM D4716 with soft foam. This is not due to any difference in the soft foam but is because the ASTM test was performed by applying the confining pressure for 1 hour before the flow test commences, whereas the ISO 12958 test commences as soon as the specimen is in place. During this 1 hour period the confining pressure causes the geotextile surface of the geocomposite to creep even further into the core of the geocomposite, which causes a greater reduction of the in-plane flow. In real life applications, the geocomposite will be subjected to confining pressures for years, not hours, and it is probable that even further in-plane flow reduction occurs as the geotextile continues to creep over the design life of the project.

The results are presented as a bar chart in Figure 3. and from this chart, the in-plane flow results for the soft foam to ASTM D4716 are surprisingly similar to the in-plane flow results for the gravel and sand backfill. This means that the soft foam accurately replicates sand or gravel backfill. The in-plane flow result for the lower permeability cover soil, however, is lower (approx 20% lower) than the in-plane flow with one soft foam rubber platen. The soft foam rubber is not soft enough to replicate the most common backfill material used in landfill capping applications. The soft foam specified in ISO 12958 significantly under estimates the geotextile intrusion and the consequent performance reduction when cover soil is placed on geocomposite drainage products. Similar findings were obtained by Zhao & Montanelli (1999) for bi-planar geonets. Therefore, the in-plane flow tests using the soft foam rubber over estimate the in-plane flow of geocomposite drains of all forms (cuspate, geonet and random fibre) when used in applications with soil backfill such as landfill caps.

Table 5. Test results for short term in-plane flow to ISO 12958

			Mean Short Term MD In-Plane Flow (l/m/sec)			
Type of Geocomposite	**Test Boundary Conditions Top - Bottom**	**Confining Pressure (kPa)**	**HG 1.0**	**HG 0.3**	**HG 0.1**	**HG 0.01**
Single Cuspate 	HARD –HARD	20 50 100 200	1.18 - 1.01 0.88	0.72 - - 0.62	0.31 - 0.27 0.22	0.05 - 0.04 0.02
	HARD –SOFT	20 50 100 200	0.97 0.82 0.71 0.52	0.47 0.39 0.28 0.17	0.25 0.19 0.14 0.07	0.04 0.03 0.03 0.015
Random Fibre Open Zig-Zag 	HARD –HARD	20 50 100 200	1.06 0.99 0.88 0.64	0.51 0.46 0.40 0.28	0.23 0.21 0.19 0.13	0.024 0.020 0.018 0.014
	HARD –SOFT	20 50 100 200	0.70 0.56 0.47 0.33	0.30 0.25 0.21 0.14	0.14 0.11 0.10 0.07	0.014 0.011 0.010 0.007

Comparing the test results presented in Table 6 with the original datasheet values shown in Table 1, it is clear that the test results are within the expectation of tolerances of the products and the accuracy of the test methods. The datasheet for the cuspated product presents values of in-plane flow with Soft Platens whereas the datasheet for the random fibre open zig-zag product shows Hard or Rigid Platen values. Hard Platen values are not particularly useful to designers as it is impossible to gauge the magnitude of the loss of in-plane flow due to geotextile intrusion. The loss of performance is product specific. The performance very much depends on the ability of the product to support the geotextile surface. A product with poor geotextile support and a slack geotextile will suffer greater loss of in-plane flow under both simulated soil (soft foam) and actual site backfill conditions than a product with a stiff geotextile. For the single cuspated geocomposite, the reduction in flow between two hard platens and one hard/one soft platen is from 17% – 40% and for the random fibre open zig-zag geocomposite, the reduction in flow is from 33% – 53% dependent on the application pressure. Similarly, for the single cuspated geocomposite, the reduction in flow between two hard platens and one hard platen/cover soil is approx 45% and for the random fibre open zig-zag geocomposite, the reduction in flow is from 55% – 80% dependent on the application pressure. Therefore the use of generic tabulated Reduction Factors based on Hard/hard Platen tests, such as those shown by Koerner (2005) should be resisted. ISO 12958 states that Hard or Rigid Platens must not be used to test geocomposite drains when the intended application has soil in contact with the geocomposite drainage layer. ASTM D4716 recommends that the actual site soil is used in the in-plane flow test whenever this is possible. The applied confining pressure can be held for a specified period of time from 15minutes to 100hours or more. This is clearly the optimum way to obtain the most realistic assessment of the in-plane flow capacity of a geocomposite drainage product especially if the water temperature used in the test is similar to that expected on site. Such tests with the intended site material are now readily available from several laboratories.

3.1 Reduction Factors

For designs with geocomposite drainage products a factor of safety is applied to the tested performance and this takes the form of partial reduction factors for the likely considerations that affect the long term performance.

$$q_{allow} = q_{tested} \; [\,1/(R_1 \times R_2 \times R_3 \times \text{etc})]$$

Rather than use in-plane flow values tested on hard/hard platens, it is proposed that values on soft or soil are used.

So the reduction factors would be

R_T = reduction for difference in water temperature
R_{INS} = reduction from soft platens to soil if appropriate
R_{CRC} = reduction for core creep
R_{CRG} = reduction for geotextile creep
R_{CC} = reduction for chemical clogging
R_{BC} = reduction for biological clogging

These factors would allow confidence that the geocomposite will provide adequate long term performance, especially with regard to the in-plane flow reduction due to geotextile intrusion.

Table 6. Test results for short term in-plane flow to ASTM D4716 with confining pressure held 1 hour

			Mean Short Term MD In-Plane Flow (l/m/sec)			
Type of Geocomposite	**Test Boundary Conditions Top -Bottom**	**Confining Pressure (kPa)**	**HG 1.0**	**HG 0.3**	**HG 0.1**	**HG 0.01**
Single Cuspate 	HARD –HARD	20	1.179	0.718	0.309	0.046
		50	-	-	-	-
		100	1.002	-	0.264	0.035
		200	0.867	0.588	0.217	0.022
	HARD –SOFT	20	0.822	0.427	0.212	0.035
		50	0.771	0.387	0.189	0.022
		100	0.700	0.357	0.174	0.020
		200	0.619	0.270	0.138	0.015
	HARD –GRAVEL	20	0.798	0.427	0.221	0.041
		50	0.746	0.394	0.201	0.037
		100	0.680	0.353	0.176	0.032
		200	0.599	0.304	0.150	0.026
	HARD –SAND	20	0.857	0.391	0.195	0.039
		50	0.701	0.342	0.169	0.032
		100	0.645	0.317	0.155	0.029
		200	0.554	0.262	0.129	0.024
	HARD –SOIL	20	0.633	0.332	0.175	0.024
		50	0.591	0.307	0.166	0.021
		100	0.547	0.282	0.148	0.019
		200	0.471	0.246	0.125	0.017
Random Fibre Open Zig-Zag 	HARD –HARD	20	1.001	0.472	0.220	0.021
		50	0.943	0.420	0.194	0.018
		100	0.816	0.377	0.179	0.017
		200	0.589	0.260	0.121	0.013
	HARD –SOFT	20	0.600	0.266	0.120	0.019
		50	0.499	0.217	0.096	0.013
		100	0.385	0.162	0.069	0.007
		200	0.227	0.086	0.034	0.004
	HARD –SOIL	20	0.440	0.199	0.092	0.014
		50	0.275	0.123	0.045	0.008
		100	0.140	0.064	0.027	0.004
		200	0.042	0.016	0.005	0.001

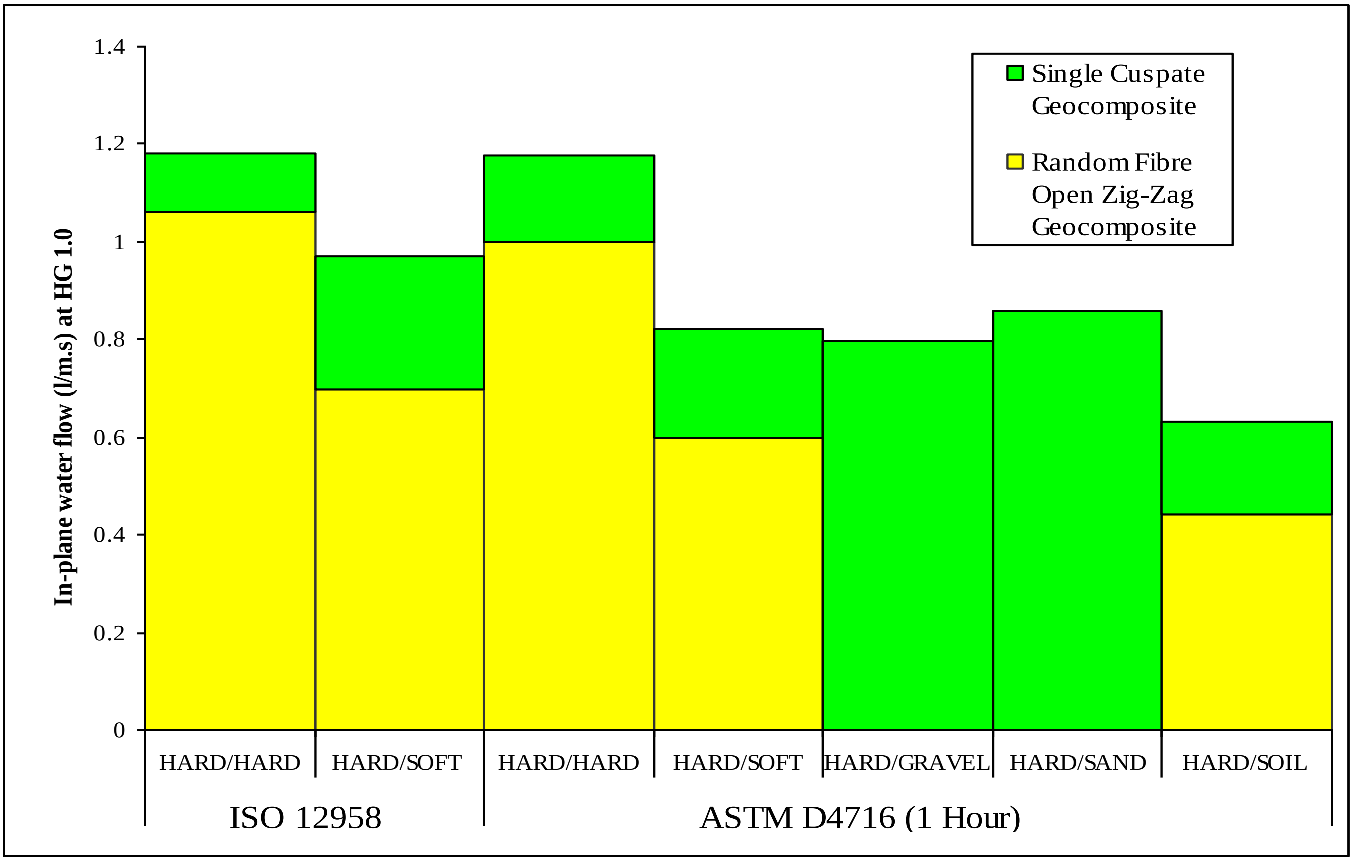

Figure 3. Bar chart of short term in-plane flow with different boundary conditions at 20kPa confining pressure

Geocomposite datasheets that present values of in-plane flow based on tests with Soft Foam Platens indicate some of the effect of geotextile intrusion into the core under the action of the confining pressure of the backfill and are a better means of product comparison than Hard/hard Platen results. If the backfill is gravel or sand, such datasheet values tested with one Soft Platen/one hard platen and 1 hour seating pressure can be used for design purposes for landfill caps on a HDPE geomembrane barrier. If the landfill cap has a GCL barrier then the datasheet should present values of in-plane flow with soft platens both sides – soft/soft. If the backfill material is a cover soil then for design purposes, a reduction factor must be applied to the Soft Platen datasheet values. These reduction factors based on the Soft Platen values will be product specific. From the test results in Table 2, a Soft Platen to soil reduction factor R_{INS} of 1.2 is suggested for the single cuspated geocomposite and a Soft Platen to soil reduction factor R_{INS} of 1.4 is suggested for the random fibre open zig-zag geocomposite.

The discrepancy between the in-plane flow performance of both geocomposites with soft foam/hard platens and soil/hard platens increases at higher confining pressures. This is the result of the combined factors of the increased intrusion of the geotextile surface into the core of the geocomposite and the further compression of the core. The effects of core compression and geotextile intrusion are shown separately in Figure 4. In Figure 4 the hard/hard flow reduction between 20kPa and 100kPa can only be due to core compression. The flow reduction between hard/hard at 100kPa and soil/hard at 100kPa must then be solely due to the geotextiel intrusion. Figure 4 clearly shows that the on both geocomposites the in-plane flow reduction due to core compression is approx 17% and the flow reduction due to geotextile intrusion under actual cover soil is a further 45% for the single cuspate and 70% for the random fibre zig-zag geocomposite. The single cuspate geocomposite appears to retain more performance than the random fibre open zig-zag geocomposite.

The confining pressure on landfill capping applications is typically 20kPa from the I metre of cover soil. This is a long term load and will have a prolonged effect on the reduction of the in-plane flow capacity of the geocomposite drainage layer. Consideration of the short term performance at 100kPa is suggested as a rapid approximation to the assessment of the long term performance under a 20kPa confining pressure.

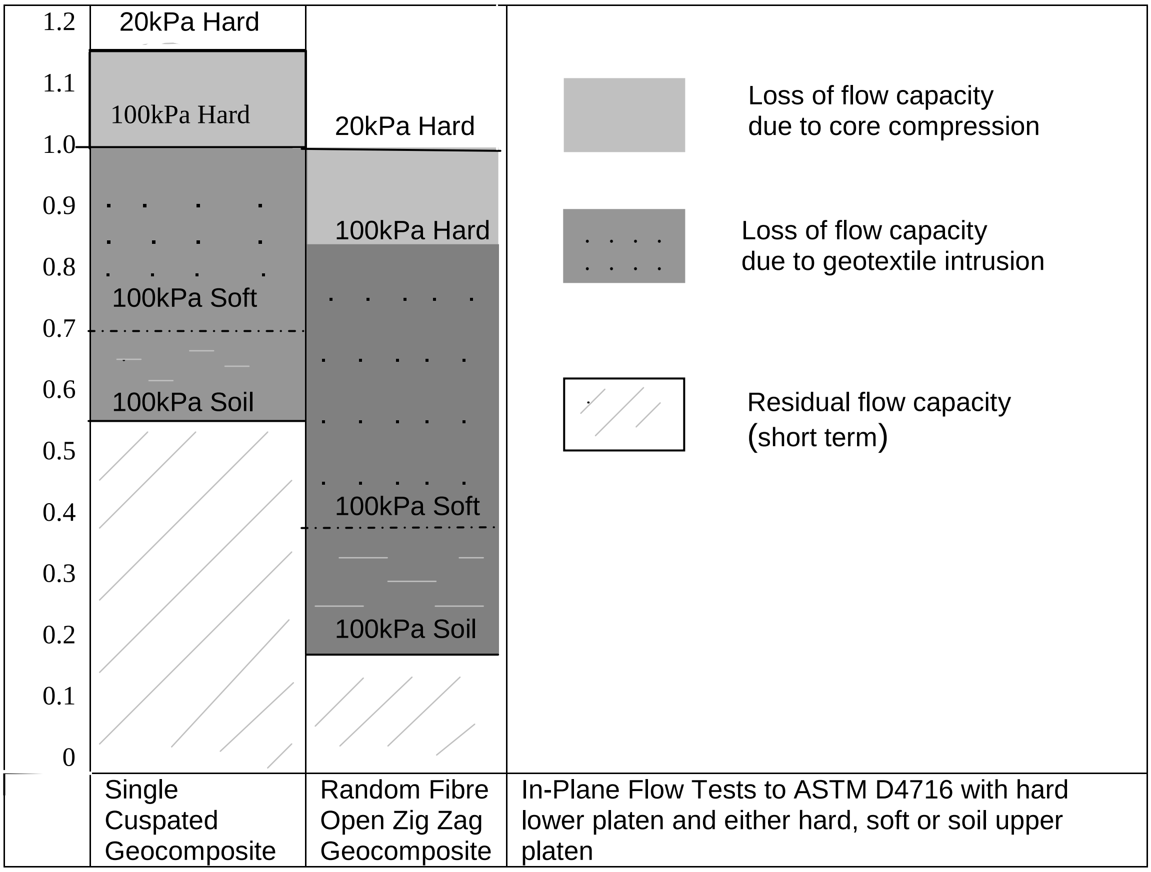

Figure 4. Bar chart of In-plane flow capacity at HG1 with 20kPa and 100kPa confining pressure

3.2 Long Term Performance

All of these results are based on short term tests and it is indicative of the longer term effect that the results to ASTM D4716 after one hour of sustained confining pressure are approx 15% lower than the corresponding ‘instant’ results to ISO 12958. Geocomposite drains are often utilised in applications with a design life of 30 to 100 years. The in-plane flow will continues to decrease during this period due to further compression of the core and intrusion of the geotextile. A partial assessment of the expected long term performance can be obtained by consideration of the creep characteristics of the geocomposite core. Creep is the reduction in thickness of the geocomposite with time under constant confining pressure. Thickness reduction can be related mathematically to the in-plane flow reduction or more precisely, the in-plane flow can be obtained by flow tests at the reduced thickness (the reduced thickness is obtained quickly by a short term overload). Creep is product specific and dependent upon the magnitude of the applied pressure. The rate of creep is low if the applied pressure is small compared to the ultimate compressive strength of the geocomposite. The stepped isothermal method (SIM) is utilised to rapidly obtain the expected thickness reduction due to creep at a particular confining pressure for periods up to 114 years. Greenwood and Young (2008) demonstrated the application of SIM to a single cuspated geocomposite drain and found creep thickness reduction at 200kPa to be approx 16% in 114 years.

The thickness reduction of the geocomposite core is one aspect but it is to be expected that the geotextile surface of the geocomposite also continues to progressively intrude into the core of the geocomposite. It is also suspected that the in-plane flow reduction due to prolonged geotextile intrusion under sustained confining pressure is greater than the reduction due to creep of the geocomposite core. Currently it has not been possible to define a methodology to rapidly determine the long term intrusion of the geotextile surface into the core of the geocomposite. It is probable that those products that have a significant amount of geotextile intrusion in the short term in-plane flow tests will suffer the greatest geotextile intrusion in the long term. It is possible that reduction factors for long term geotextile intrusion would be an order of magnitude higher than those currently used for other reduction factors such as chemical clogging and biological clogging.

4. CONCLUSIONS

- Geotextile intrusion has the biggest reduction on geocomposite drainage in-plane flow performance (2 – 5 times the in-plane flow reduction due to compression of the core)
- Geotextile intrusion is product specific and is most significant with soil backfill (difference of between 50% and 95% reduction)
- ISO 12958 stipulates that Hard Platen values are used solely for applications on hard surfaces
- Datasheets with values of in-plane flow with Soft Platens are a better means of product comparison than datasheets with Hard Platens
- The soft foam specified in ISO 12958 significantly under estimates the effect of performance reduction when cover soil is placed on geocomposite drainage products
- Performance in-plane flow tests to ASTM D4716 with site specific backfill are the most reliable, readily available and to be recommended.
- The long term effect of geotextile intrusion requires further study

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