PROTECTION EFFICIENCY OF NONWOVEN POLYPROPYLENE GEOTEXTILES

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Abstract: Protection of a geosynthetic barrier during installation, load application and the lifetime of a project can be effectively provided by a geotextile in contact with the barrier on the side where the loads are to be applied. European Standards specify index tests for comparative evaluation of the protection efficiency of geotextiles against impact loads (EN ISO 13428) and long term static point loads (EN ISO 13719). This investigation is aimed toward providing a quantitative evaluation of the protection efficiency of nonwoven polypropylene geotextiles based on results obtained for a relatively large number of samples. Tests were conducted according to EN ISO 13428 on 70 geotextiles (needle-punched, heat-bonded, post-treated) made of staple fibers or continuous filament, with mass 115 to 2200 g/m^2 and thickness 0.50 to 11.90mm. Sixteen samples, representative of the whole group, were also tested according to EN ISO 13719. Base-line values were obtained, for normalisation purposes, by conducting tests without a geotextile protector. The protection efficiency of the geotextiles according to EN ISO 13428 (percent residual thickness of the lead plates in the impact areas) ranged between 17% and 89%. An excellent linear correlation (R^2=0.95) was obtained between residual thickness and geotextile mass per unit area. Measurement of local strain at the impact areas was made to facilitate comparisons with local stain measurements according to EN ISO 13719. Based on local strain measurements (according to EN ISO 13719) the protection efficiency values of the geotextiles were found to range between 25.0x103 and 66.7x103 kN/m^2. Very good correlations (R^2 over 0.85) were obtained between the protection efficiency values and geotextile physical and mechanical properties. Selection of an appropriate geotextile depends on the anticipated magnitude of the external load and on the specified allowable geomembrane deformation. Relatively heavy geotextiles (mass over 1500 g/m^2) are required to protect geosynthetic barriers when allowable deformations are limited to less than 2%.

Keywords: Nonwoven geotextiles, geomembrane, protective layer, index testing

INTRODUCTION

Survivability of geomembranes used as liners in a project or structure requires adequate protection during installation and construction, during load application and during the lifetime of the project. Protection can be effectively provided by a geotextile in contact with the geomembrane on the side where the loads are to be applied. It is common practice to use a nonwoven needle-punched geotextile for geomembrane protection. In general, the protection efficiency of nonwoven geotextiles increases with increasing mass per unit area and increasing mechanical properties. However, significant differences in the protection efficiency may be observed (Jones et al. 2000) between geotextiles with the same mass per unit area.

The level of protection provided to a geomembrane by a geotextile has been investigated in the past by testing various geotextile – geomembrane combinations (a) "in-isolation" by conducting tensile strength, puncture resistance or impact resistance tests (i.e. Koerner et al. 1986, Lafleur et al. 1986, Puhringer 1990) and (b) in specially constructed equipment by applying static point loads through natural aggregate or through geometrically specified elements (i.e. Laine et al. 1989, Motan et al. 1993, Saathoff et al. 1994, Brummermann et al. 1994, Zanzinger 1996, Zanzinger and Gartung 1998, Jones et al. 2000, Gallagher et al. 1999). Based on available information, it can be observed that:
(a) There are no guidelines for the selection of a geotextile, based on its physical and/or mechanical properties, in order to protect a geomembrane against impact damage. An empirical relationship (Koerner 2005) is available in order to determine the mass per unit area of a geotextile for puncture protection of specific geomembranes.
(b) For long-term protection, some national standards require the use of geotextiles with very high mass per unit area of 2000g/m^2 to 4000g/m^2 (Heerten 1993, Seeger and Muller 1996) while other guidelines suggest lower values in the range of 350g/m^2 to 550g/m^2 (Corbet and Peters 1998). Some field observations (Reddy et al. 1996, Reddy and Saichek 1998) indicate good protection with even lighter geotextiles (270g/m^2).
(c) Previous investigations tested a small number of geotextiles, employed different testing equipment and applied different testing procedures. Accordingly, a mostly qualitative synthesis of available results can be obtained.

During the installation and construction phases, geomembranes should be protected against the damaging action of impact loads such as rocks, other materials and hand-held equipment falling on them. The worst possible condition is when the geomembrane rests on a hard, unyielding surface. European Standard EN ISO 13428, approved in 2005, describes an index test for the determination of the protection efficiency provided by a geotextile to a geomembrane resting on a hard surface and exposed to the impact load of a hemispherical object. When a geomembrane is placed at the base of a fill of significant height, protection against the mechanical long term effects of static loads is necessary. European Standard EN ISO 13719, approved in 2002, specifies an index test to determine the efficiency with which a geotextile will protect a geomembrane against the mechanical long term effects of static point loads.

The laboratory investigation reported herein is based on the application of these standard procedures (EN ISO 13428, EN ISO 13719) in order to test a large number of nonwoven polypropylene geotextiles. Scope of the investigation is to supplement available data on the protection efficiency of nonwoven geotextiles and to provide adequate documentation of the relationship between protection efficiency and geotextile physical and/or mechanical characteristics.

MATERIALS AND PROCEDURES

According to EN ISO 13428, the index test to quantify the protection efficiency of a geotextile against impact damage is conducted by subjecting a test specimen to an impact load produced by a rigid probe with a hemispherical head (20mm diameter). The falling height is (1±0.01)m and the mass of the probe is (1000±2)g. The specimen lies on a rigid support consisting of a 40mm thick steel plate. A lead plate with nominal thickness of (1.8 ± 0.2)mm is placed between the steel plate and the specimen. The residual thickness, S_r(%), of the lead plate in the impacted areas, expressed as a percent of the original thickness, is an index of the protection efficiency provided by the geotextile. Shown in Figure 1a is the laboratory testing frame used for conducting the tests reported herein. The standard probe with a mass of 1000g and the rigid support with lead plate and geotextile on top are shown in Figures 1b and 1c, respectively.

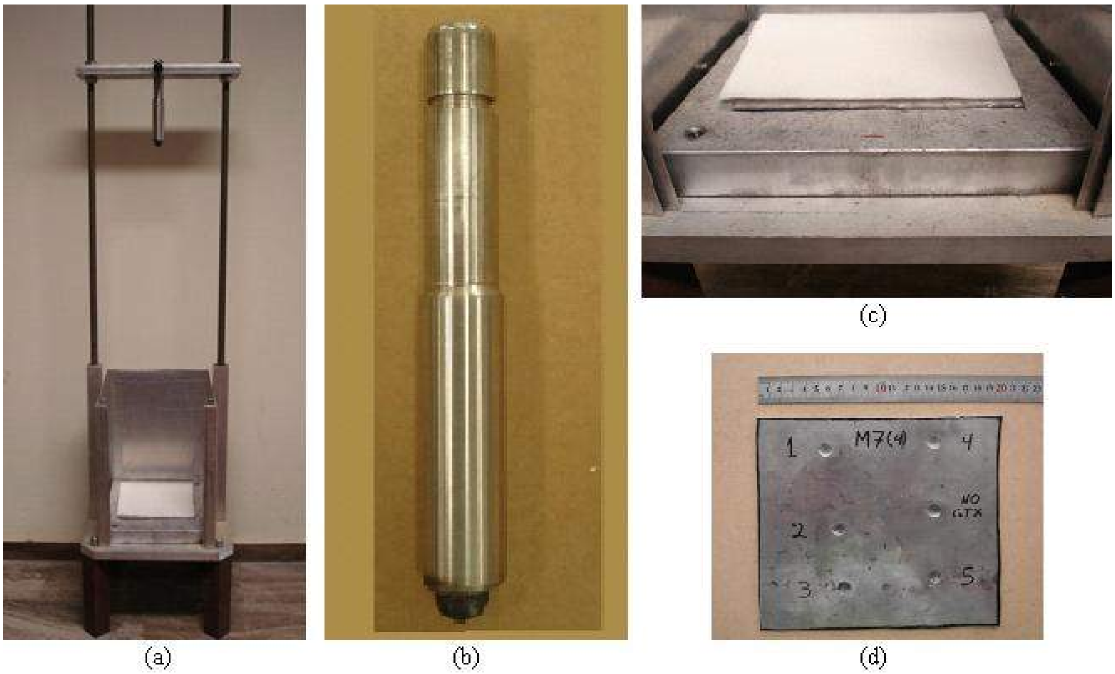

Figure 1. Impact damage testing: (a) loading frame, (b) rigid probe, (c) rigid support and (d) impacted lead plate

According to EN ISO 13719, the protection efficiency index test is conducted in a smooth sided steel cylinder with an internal diameter not less than 300mm. The geotextile is placed on a soft sheet metal disc that serves to capture the geotextile deformations. The metal disc rests on a 25mm thick rubber pad with a hardness of 50±5 Shore A. Load (300 kPa, 600 kPa and 1200 kPa) is applied through a simulated standard aggregate (20mm diameter steel balls, 150mm minimum depth) for 100h. The protection efficiency, PE (kN/m^2), is calculated based on the average of the strains measured for the three largest depressions on the soft metal disc. An overall view of the laboratory equipment used for conducting the tests reported herein is shown in Figure 2a. The steel cylinder had an internal diameter of 305mm and a height of 300mm. The rubber pad had a hardness of 55 Shore A. The metal disc was made of lead and complied with the specifications set by the standard. Approximately 1500 steel balls were used to form a 150mm thick layer. The upper loading plate rested on a sand layer that was separated from the steel balls by a thin geotextile. Due to equipment limitations the highest applied load was 1100 kPa instead of the 1200 kPa specified by the standard. Appropriate dial gage and support device, shown in Figure 2b, were used to define the limits of the deformations and to measure vertical displacements on the lead plate.

For the purposes of the experimental investigation reported herein, geotextile specimens were taken from large size samples obtained from ten different manufacturers. The size of the samples ranged from 4m^2 to 12m^2 with a width equal to the standard production roll width of each manufacturer. Some manufacturers provided samples covering two different groups of their products. The number of different geotextiles (number of grades per product series) tested ranged from three to eight, yielding a total of 70 samples from 13 different product series. Only nonwoven, polypropylene geotextiles were tested. The group consisted of needle-punched with staple fibers (53%), needle-punched with continuous filaments (19%), needle-punched with staple fibers and thermally post-treated (14%) and heat-bonded (14%) products. In order to avoid the use of commercial names, a generic notation is used (i.e. M1) to identify manufacturers and product series. Numbers in parenthesis next to an identification code, i.e. M1 (6), indicate the number of different geotextile grades tested in that series. Letters next to the identification code are used to identify each geotextile in a series (i.e. M2a). The nominal ranges of physical and mechanical properties values for the geotextiles tested are presented in Table 1.

(a) (b)

Figure 2. Long-term protection testing: (a)overall view of equipment and (b) deformation measuring system and lead plate

All geotextiles were tested according to EN ISO 13428 to obtain lead residual thickness values. To obtain base-line values, tests were also conducted without placing a geotextile over the lead plate. An example of impacted lead plate is shown in Figure 1d. Ten geotextiles, representative of the range of physical properties of the whole group, were selected to investigate the effect of support rigidity by incorporating a rubber pad with properties as specified in EN ISO 13719. To evaluate long-term protection efficiency, tests were conducted according to EN ISO 13719 on 16 geotextiles that were made of staple fibers (five manufactures) or continuous filament (one manufacturer). One geotextile series was thermally post-treated on both surfaces. An example of deformed lead plate is shown in Figure 2b. To obtain base-line values, tests were also conducted without incorporating a geotextile in the apparatus.

Table 1. Physical and mechanical properties of geotextiles

Geotextile Series	μ_A * (g/m^2)	t † (mm)	T_f ‡ (kN/m^2)	F_p § (kN)
M2 (7)	120 – 520	1.0 – 4.0	6.8 – 36.7	1.5 – 7.2
M4 (6)	135 – 405	1.2 – 3.1	11.1 – 32.2	1.8 – 5.3
M6 (6)	350 – 2100	3.7 – 9.3	20.0 – 114.0	3.0 – 19.0
M7 (7)	320 – 1200	3.2 – 8.0	11.6 – 62.0	2.0 – 8.5
M10 (4)	300 – 2000	4.3 – 9.7	17.0 – 93.5	2.7 – 14.5
M11 (3)	500 – 1200	4.1 – 10.0	15.0 – 32.5	2.5 – 7.0
M12 (4)	180 – 370	1.3 – 2.2	11.4 – 27.0	2.0 – 4,6
M13 (8)	105 – 325	1.0 – 2.9	9.5 – 24.0	1.5 – 3.9
M14 (5)	600 – 1200	4.5 – 8.3	35.0 – 58.0	6.1 – 10.3
M15 (6)	136 – 375	0.47 – 0.85	8.6 – 30.1	1.4 – 4.5
M16 (4)	180 – 335	0.85 – 1.50	9.5 – 23.7	2.2 – 4.3
M17 (6)	120 – 500	1.0 – 3.3	8.0 – 34.0	1.2 – 5.8
M18 (4)	500 – 1300	4.7 – 8.5	14.0 – 31.5	2.3 – 8.2

* Mass per unit area
† Thickness
‡ Average tensile strength in MD and CD directions
§ Static puncture (CBR) strength

RESULTS ON IMPACT DAMAGE

The results obtained for each series of geotextiles tested, were used in order to obtain correlations between the residual thickness, S_r(%), and the physical properties of the geotextiles (mass per unit area, μ_A, and thickness, t). The values used for physical properties are those obtained during each test, as specified by EN ISO 13428 and may differ from the nominal values presented by the manufacturers. As a first order approximation, a linear relationship was used and the correlations obtained are summarized in Table 2. Similarly, linear correlations were obtained for the complete set of data as well as for groups of data representing products which are (a) needle-punched with staple fibers, (b) needle-punched with continuous filaments, (c) needle-punched with staple fibers and thermal post-treatment of both surfaces and (d) heat-bonded.

The linear correlation between residual thickness, S_r(%), and geotextile mass per unit area, μ_A, appears to be very good for most of the geotextile series tested. For one series a low value for the correlation coefficient (R^2=0.514) was obtained while for ten out of thirteen series the values were over 0.900 and as high as 0.997. The correlation between

Table 2. Correlations between residual thickness, S_r(%), and geotextile physical properties (impact damage tests)

Geotextile Series	$S_r(\%)=A\cdot\mu_A+B$			$S_r(\%)=A\cdot t+B$		
	A	**B**	**R_2***	**A**	**B**	**R^{2*}**
M2 (7)	0.0297	17.10	0.840	5.02	15.02	0.914
M4 (6)	0.0442	12.41	0.725	4.17	13.41	0.837
M6 (6)	0.0317	16.46	0.985	7.95	7.86	0.983
M7 (7)	0.0346	17.38	0.947	7.86	3.29	0.966
M10 (4)	0.0310	11.73	0.994	11.22	30.62	0.997
M11 (3)	0.0348	13.80	0.997	4.57	3.13	0.671
M12 (4)	0.0267	15.57	0.987	5.79	12.98	0.866
M13 (8)	0.0348	13.24	0.957	3.76	12.87	0.918
M14 (5)	0.0474	11.22	0.986	6.38	11.68	0.855
M15 (6)	0.0304	15.27	0.902	22.22	8.66	0.881
M16 (4)	0.0258	15.89	0.514	6.77	14.72	0.294
M17 (6)	0.0283	18.49	0.913	5.31	15.67	0.916
M18 (4)	0.0323	18.77	0.989	6.65	3.36	0.287

* Correlation coefficient

residual thickness, S_r(%), and geotextile thickness was not as good. Only six out of thirteen series had correlation coefficient values over 0.900 while for two series the value was below 0.300.

Presented in Figure 3 are the correlations of residual thickness, S_r(%), with mass per unit area, μ_A, and thickness, t, for the complete set of data. It is confirmed that correlations with geotextile mass per unit area are qualitatively superior to correlations with geotextile thickness. Using the overall correlation with mass per unit area, the expected residual thickness for each geotextile was computed and the results were compared with the measured value. The resulting error ranged between ± 5%, ± 10% and ±20% for 30%, 72% and 97% of the geotextiles, respectively. Accordingly, the linear relationship obtained has a very good overall predictive capability. However, significant differences may be observed if comparisons of residual thickness values are made between individual geotextiles with similar mass per unit area, yielding a ratio between corresponding residual thickness of up to 1.2 to 1.3.

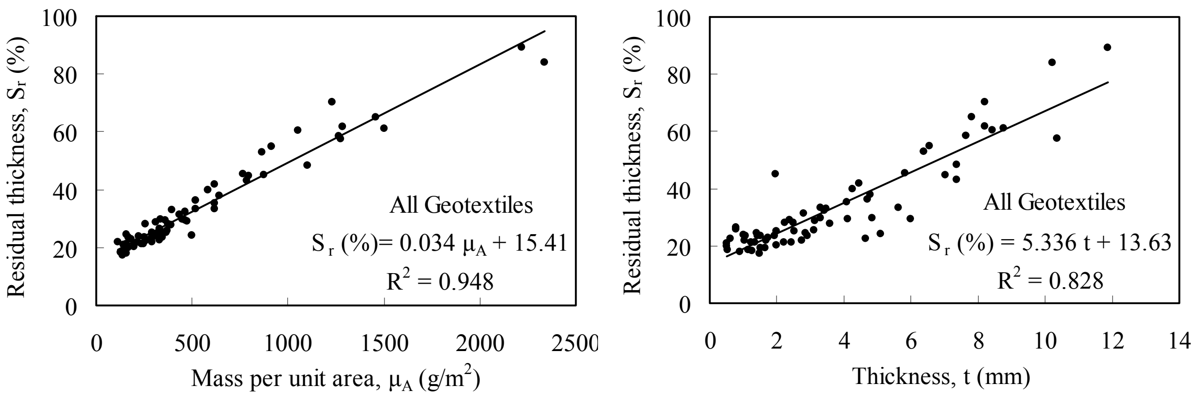

Figure 3. Overall correlations of residual thickness with geotextile physical properties (impact damage tests)

The remaining (residual) thickness of the lead plate used to conduct tests according to EN ISO 13428 when no geotextile is placed over it, should be considered as the base-line value. During this investigation, an extra drop of the probe was allowed after removal of the geotextile specimen on forty-five different lead plates. The average residual thickness of the lead plate without geotextile was computed to be equal to 15.20%. This value is in very good agreement with the value of 15.41% obtained through the linear correlation shown in Figure 3. However, the results of correlations per geotextile series, summarized in Table 2, indicate a variation of the base-line value between 11.22% and 18.77%. This fact suggests a difference in behavior between different product series that may be attributed to the effect of differences in raw materials used and manufacturing processes.

In an attempt to evaluate the effect of differences in raw materials used and manufacturing processes employed, the available data were separated in four groups and new correlations were obtained of residual thickness versus mass per unit area. The results, summarized in Table 3, indicate good to excellent correlations for the four groups of products. It can be observed that: (a) heat-bonded products yielded lower residual thickness values (provided the lower protection efficiency) compared to the other three geotextile types, (b) thermal surface post-treatment offers a small advantage over heat-bonded products, but no advantage when compared to the other two types of products, (c) if a geotextile with relatively low mass per unit area (less than 400g/m^2) is to be used, then needle-punched, staple fiber products should be preferred and (d) if for specific reasons, such as long term protection, a heavy geotextile is to be used, continuous filament products may offer the highest protection against impact damage.

Table 3. Correlations of residual thickness, $S_r(\%)$, with mass per area for different types of geotextiles (impact tests)

Nonwoven geotextile type	**$S_r(\%)=A\cdot\mu_A+B$**		
	A	**B**	**R^2**
Needle-punched, staple fibers	0.0319	16.53	0.963
Needle-punched, continuous filament	0.0480	10.51	0.996
Needle-punched, post-treated	0.0275	17.36	0.755
Heat-bonded	0.0291	15.40	0.765

RESULTS ON LONG-TERM PROTECTION

The average of the strains measured for the three largest depressions on the lead plate after each test were used to prepare stress-deformation graphs and obtain the index protection efficiency of each geotextile tested according to EN ISO 13719. Typical stress-deformation graphs are shown in Figure 4. The required linear relationship was obtained with the constraint that the line passes through the origin of the axes in order to avoid disadvantages in terms of physical interpretation. In general, the linear correlations obtained were very good to excellent as judged by the correlation coefficient values, R^2, which ranged between 0.903 and 0.999. Measured deformations and computed protection efficiency are summarized in Table 4. Also presented in Table 4 are the results obtained from tests conducted without incorporating a geotextile in the apparatus and are considered as base-line values.

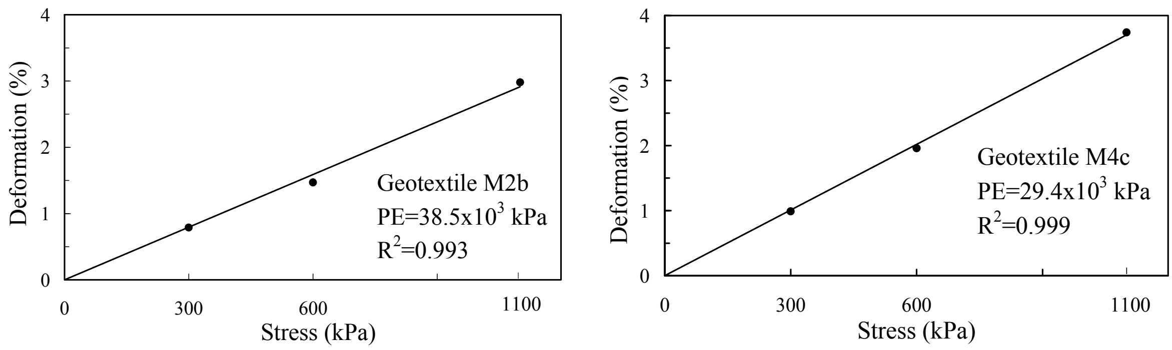

Figure 4. Typical stress-deformation graphs from long-term protection tests

As a first order approximation, a linear relationship was used to obtain correlations between protection efficiency and geotextile physical properties and the results obtained are shown in Figure 5. It can be observed that the correlation with geotextile mass per unit area is qualitatively superior to the correlation with geotextile thickness. Correlations with major mechanical properties (tensile strength and static puncture strength) were, for all practical purposes, equivalent to the correlation with mass per unit area. This observation was anticipated since excellent correlations between mass per unit area and mechanical properties have been documented for nonwoven polypropylene geotextiles (Atmatzidis et al. 2004). Finally, it should be noted that the experimentally obtained base-line value ($23.8x10^3$kPa) is in good agreement with the values obtained by the linear correlations.

Table 4. Deformation and protection efficiency results (long-term protection tests)

Geotextile	**Deformation (%) for stress (kPa)**			**Protection efficiency ($x10^3$kPa)**
	300	**600**	**1100**	
M2a	1.10	1.67	4.13	28.6
M2b	0.79	1.47	2.98	38.5
M2c	0.96	1.42	3.06	37.0
M4a	1.06	1.87	3.52	31.2
M4b	1.29	1.91	3.60	30.3
M4c	0.99	1.96	3.74	29.4
M6a	1.10	2.03	3.45	31.2
M6b	0.60	1.60	2.76	40.0
M6c	0.35	0.96	1.71	66.7
M11a	0.63	1.61	3.05	37.0
M11b	0.63	1.45	2.03	52.6
M13a	1.14	1.85	4.57	25.6
M13b	0.89	1.61	3.31	34.5
M17a	0.97	2.20	4.50	25.0
M17b	0.58	1.50	3.64	32.2
M17c	0.45	1.28	2.61	43.5
NoGTX	1.47	2.36	4.66	23.8

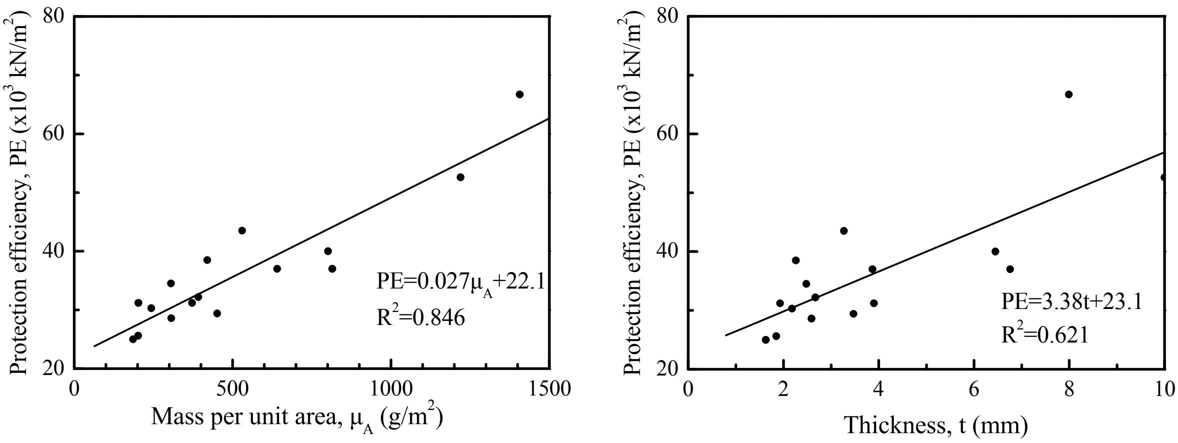

Figure 5. Correlations of long-term protection efficiency with geotextile physical properties

Using the overall correlation with mass per unit area, the expected protection efficiency was computed for each geotextile and the results were compared with the measured value. The resulting error ranged between ±10% and ±20% for 56% and 100% of the geotextiles, respectively. Accordingly, the linear relationship has an acceptable overall predictive capability. However, it should be pointed out that significant differences may be observed if comparisons of protection efficiency are made between individual geotextiles with similar mass per unit area (or similar mechanical properties). Such differences are in the range of up to $6x10^3$ kPa and yield a ratio between the protection efficiencies of similar geotextiles (same mass and/or mechanical properties) in the range of up to 1.2.

CORRELATION BETWEEN PROTECTION INDICES

The correlations of both the impact damage index, S_r(%), and the long-term protection index, PE, with mass per unit area shown in Figures 3 and 5 may be used to obtain a relationship between the two indices. However, it is preferable to use the actual results obtained by conducting both types of index tests on the same geotextiles (16 samples) to obtain a correlation between the two indices. This correlation is shown in Figure 6, indicating a relatively good agreement ($R^2 \approx 0.80$) between them. Using this correlation, the expected long-term protection efficiency was computed using the impact damage index values obtained from testing and the results were compared with the measured value. The resulting error ranged between ±10% and ±25% for 50% and 100% of the geotextiles tested while the average error was ±12%, indicating an acceptable correlation between the two indices.

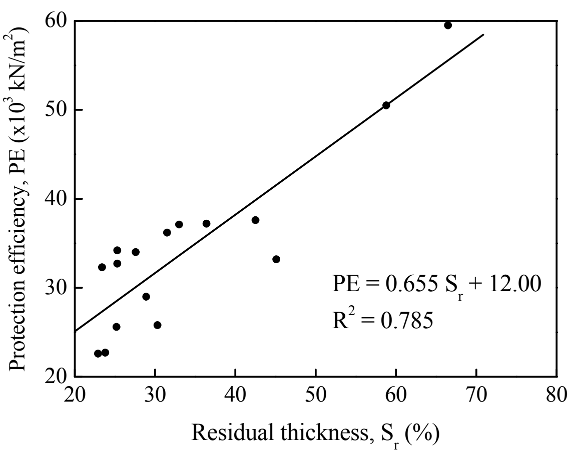

Figure 6. Correlation between protection indices

INTERPRETATION IN TERMS OF DEFORMATION

The loads applied on geomembranes are often dictated by the maximum allowable strains that are set by standards or specifications. It is frequently specified that tensile deformation under long-term loading should not exceed a value of 2%. From this perspective, it is of interest to examine the implications of the data generated during this investigation by assuming that the strains measured on the lead plate are those to be experienced by a geomembrane. To facilitate comparisons, the deformations of the lead plate from impact damage tests were measured in the same manner as the deformations on the lead plate from long-term protection tests. The deformations due to impact ranged between 0.32% and 5.75%, increasing with decreasing mass per unit area of the protecting geotextile. If a safely factor is defined by the ratio of allowable deformation (2%) to measured deformation, then this factor has values ranging between 6.25 and 0.35. Similarly, safety factors can be computed for the deformations caused by long-term protection tests (as reported in Table 4). It can be observed that, for low anticipated external load (300 kPa), all geotextiles tested provide positive protection regardless of their properties. However, the degree of protection varies since the safety factor values range between 1.55 and 5.71. Similarly, for intermediate anticipated external load (600kPa), most of the geotextiles tested provide positive protection with a safety factor between 1.02 and 2.08 while two geotextiles fail to provide the required protection. At high external loads (1100 kPa), only one of the geotextiles tested provided some protection with a safety factor of 1.17 while for the rest of the geotextiles tested the safety factor ranges between 0.98 and 0.44.

The rigidity of the support on which the geosynthetics are placed obviously has a significant effect on the protection efficiency against impact damage. As the support beneath the geosynthetics deforms, a greater amount of impacting energy can be absorbed and the impact damage will be less severe. For soil supported geotextiles, Koerner (2005) recommends impact energy reduction factors ranging from 30 to 3 when the CBR value of the supporting soil ranges from 0 to 20. A validation of this beneficial effect was obtained by testing ten geotextiles that are representative of the full range of the geotextiles tested. A rubber pad used for long-term protection efficiency testing according to EN ISO 13719 was placed over the steel plate that is the standard support for impact damage index testing. The residual thickness values obtained ranged between 76% and 88% and the corresponding deformations ranged between 1.66% and 0.81%, with safety factors ranging between 1.2 and 2.5. Accordingly, excellent protection can be obtained by using geotextiles in the low range of mass per unit area values if the support of the geosynthetics can assist in the absorption of an amount of the impacting energy.

The effect of geotextile mass per unit area on the measured deformations is shown in Figure 7. It can be observed that, for the selected limiting deformation value of 2%, a relatively heavy geotextile with mass per unit area over 1500g/m^2 should be employed in order to provide adequate protection if the external load is high (1100 kPa). However, for intermediate and low external loads (600kPa and 300kPa) protection can be provided by geotextiles with mass per unit area as low as 200g/m^2 depending on the specified degree of protection.

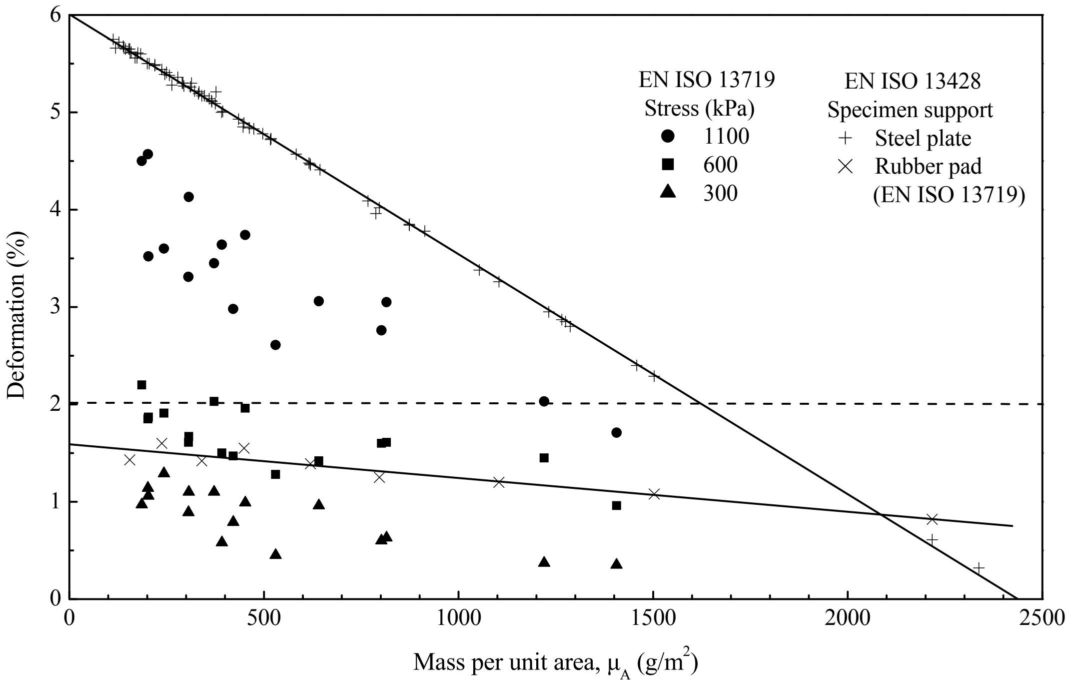

Figure 7. Effect of geotextile mass per unit area on deformations

CONCLUSIONS

Based on the results obtained and the observations made during the experimental investigation reported herein, the following conclusions may be advanced with respect to the protection efficiency provided by nonwoven polypropylene geotextiles against impact loads and long-term static loads:

1. Very good to excellent linear correlations exist between the mass per unit area of geotextiles and the protection they provide to geomembranes against impact loads, as measured by the residual thickness index of Standard EN ISO 13428.
2. A good linear correlation exists between the mass per unit area of geotextiles and the protection they provide to geomembranes against the long term effects of static point loads, as measured by the protection efficiency index of Standard EN ISO 13719
3. The two indicators (indices) of protection against impact loads and against long-term static point loads are correlated and acceptable, first order, predictions may be made for one if the other is known.
4. Nonwoven, needle-punched products are to be preferred, with continuous filament products having an advantage over staple fiber products at higher mass per unit area ranges for protection against impact damage.
5. The protection efficiency indices (impact and/or long-term) obtained for geotextiles with similar physical and/or mechanical properties may differ by up to 20% to 30%.
6. Support rigidity should be evaluated since its effect is significant on the protection provided by geotextiles.

Evaluated for the same, deformable, support, protection against long-term static point loads dominates compared to protection against impact loads.
7. Selection of a geotextile for long term protection depends on the magnitude of the anticipated external load and on the maximum allowable deformation of the protected geosynthetic.

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