DRAINAGE GEOCOMPOSITES : RELATION BETWEEN WATER FLOW CAPACITY AND THICKNESS IN THE LONG TERM

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ABSTRACT: The creep behaviour of geosynthetics, that is, the time-dependent decrease of their thickness under compressive or compressive+shear loading, under constant stresses, has been the subject of many investigations. Similarly, many studies have attempted to identify the factors affecting transmissivity, and therefore the flow capacity of drainage geocomposites. Among these products, those having a geogrid as a draining core have been investigated most thoroughly. In the present work, we considered 4 types of drainage geocomposites, with different geospacers. We have succeeded in evaluating their long-term water flow capacity in the plane, using the compressive creep and flow capacity European standards. First we developed an experimental approach to validate our method. It consists in reasoning on the basis of the time-dependent product thickness decrease, making it possible to calculate, from the short-term flow capacity, their long-term flow capacity. In a second step, we deduced from our results the reduction factors that, when applied to the short-term flow capacity (according to the standard), allow us to estimate the long-term flow capacity. By comparison, we have demonstrated that the reduction factors given in the current literature concern essentially incompressible or semi-compressible products. Accordingly, for the compressible product under study, we revealed that reduction factors are far greater, on the order of twice the previous ones.

1 INTRODUCTION

The design of the water flow capacity of drainage geocomposites is no easy matter. The difference between the flow capacity of the product measured in the laboratory (Q_m) and the long-term in soil flow capacity (Q_{LTIS}) may be considerable. Many studies, mostly concerning geogrids, have determined that many factors affect Q_{LTIS} : the hydraulic gradient, the kind of the materials enclosing the product in situ (concrete, soil, waste, etc) linked with the intrusion of the filter geotextile in the draining core, the stress applied (normal compressive and shear loadings), the creep of the geocomposite, the chemical and biological clogging, etc.

Zanzinger and Gartung (1998) have demonstrated that reduction factor due to the creep of the geospacer is the greatest factor affecting the flow rate. The EN ISO 12958 standard also underscores the strong effect of time-dependent compressibility of a product on its flow rate.

The creep of a geosynthetic results from its time-dependent decrease in thickness under constant stress. The decrease in thickness of a geosynthetic implies a decrease in its transmissivity (Giroud, 2000), defined as :

$$\theta = k.T_g \qquad (1)$$

where θ is the transmissivity, k the hydraulic conductivity and T_g the thickness of the geosynthetic.

Therefore, the creep phenomenon yields to a reduction in transmissivity, first directly by decreasing the product thickness T_g and secondly, more indirectly, by decreasing the conductivity k when T_g is lowered.

In the present work, we have investigated the relation between the compressive creep of drainage geocomposites and the time-dependent decrease of their flow capacity. Campbell and Wu (1994) showed that reasoning based on a flow capacity rather than on transmissivity was better to estimate the flow rate of geocomposites. Moreover, the approach of the EN ISO 12958 standard has been used, based on flow capacity. The water flow capacity and the transmissivity are inter-related by:

$$Q = \theta .i \qquad (2)$$

where Q is the water flow capacity and i the hydraulic gradient. In the experimental plan, the hydraulic gradient has been fixed equal to 1.

Luciani (1985) established that drainage geocomposite creep behaviour depends considerably on the manufacturing process. For this reason, we have decided to carry out the study on 4 drainage geocomposites varying by the type of geospacers :

- C1 (compressible) : geotextile draining core associated on both sides with a needle-punched nonwoven geotextile
- C2 (semi-compressible) : draining core consisting of a random network of monofilaments, covered on both sides by a thermo-bonded geotextile
- NC1 (incompressible): draining core consisting of a PEHD extruded grid covered on both sides by a thermo-bonded geotextile
- NC2 (incompressible): draining core consisting of a symmetrical thermoformed sheet of PEHD covered on both sides by a thermo-bonded geotextile

Therefore, the experimental plan included two phases : first, we determined the compressive creep properties of the products to obtain their long-term thickness. So we carried out creep tests following EN 1897 both under compressive and compressive+shear loading. Secondly, the water flow capacity was measured for all products under various stresses and then the evolution of their flow capacity according to their thickness was deduced. Thus, we were able to calculate the long-term flow capacity of the products, based on their long-term thickness.

2 CREEP TESTS

2.1 *Tests procedures*

Two sets of tests were performed following EN 1897 :

- first set with a combination of normal compressive loading and shear loading. The normal stress applied was 50, 100, and 200 kPa on a 504 hours long time period. The shear stress was 20% of the normal one ;
- second set using just the same normal stress, for one hour.

The tests were limited respectively to a duration of 504 hours and 1 hour instead of the 1008 hours specified by the standard because almost all the product thickness reduction occurs during the first hour of testing and at the term of 1 hour, the linear part of the creep curve was already reached.

The single compressive creep curves were plotted after 1 hour and up to 504 hours, using linear extrapolation method.

2.2 *Tests results*

Table 1 shows the thickness of the samples of the 4 products tested, measured at 5 kPa normal stress according to the EN 964-1 standard.

Table 1 Initial geocomposite thickness

Products	Initial thickness (mm) at 5 kPa
C 1	6.8
C 2	3.9
NC 1	5.1
NC 2	7.0

The results of the tests according to the 2 methods are presented in figures 1 to 4. The solid lines represent the measurements, and the dotted line curve extensions have been extrapolated (the equation of the linear extrapolation is indicated in the figures).

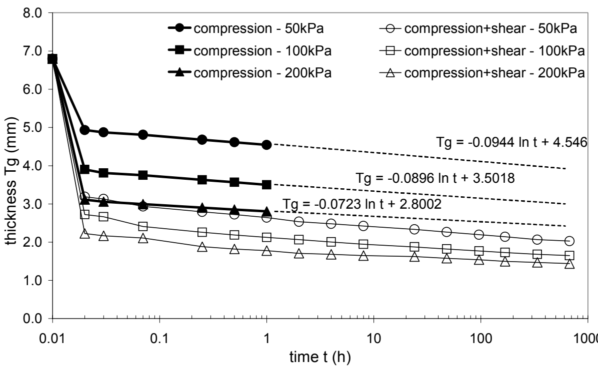

Figure 1 Changing thickness according to time for C1

In figure 1, the compressive curves indicate that the thickness of the product is greater in the case of single compressive load than in the compressive+shear load one, for the tested stress ranging from 50 to 200 kPa. The shear effect on thickness occurs instantaneously and can be observed as soon as load is applied.

For instance, at a normal load of 100 kPa, the thickness of C1 after one hour testing is 3.5 mm whereas, for a normal load of 100 kPa + a shear load of 20 kPa, this thickness is reduced to 2.1 mm after the same time.

One can observe that the thickness of C1 (figure 1) under a load of 50 kPa + 10 kPa shearing gives the same thickness value for the product as for a single normal strain of 200 kPa.

Similarly, at a normal load of 50 kPa, the thickness of C2 (figure 2) is 3.4 mm whereas under a normal load of 50 kPa + a shear load of 20 kPa, it is reduced to 3.2 mm after one hour of testing.

On the contrary, it can be seen that the thickness curves obtained by the two loading method are similar. The thickness reduction is approximately the same over a given period of time.

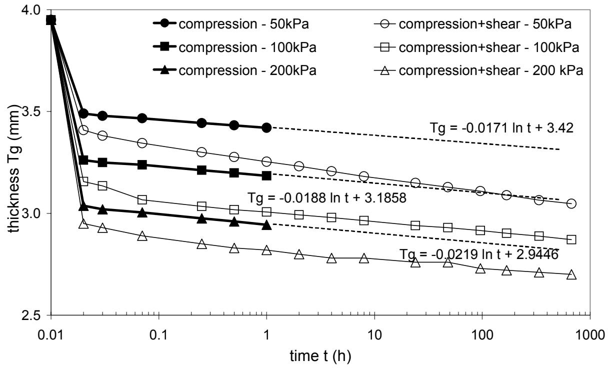

Figure 2 Changing thickness according to time for C2

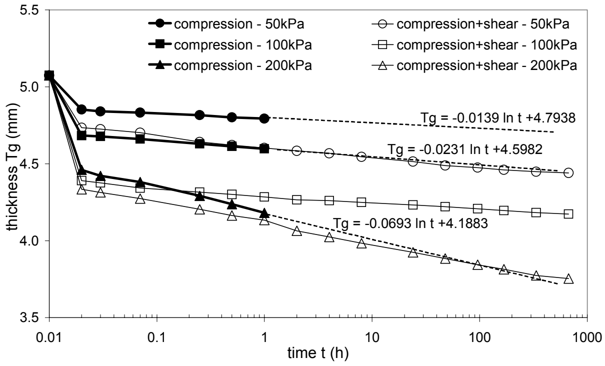

Figure 3 Changing thickness according to time for NC1

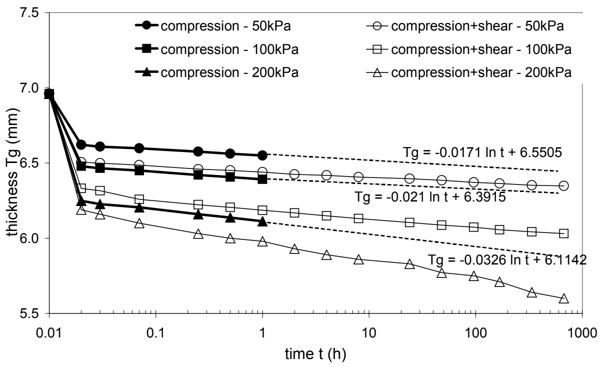

Figure 4 Changing thickness according to time for NC2

The curves obtained for the products NC1 and NC2 (figures 3 and 4) revealed that the shear effect on creep, although present, is quite low.

The thickness of NC1 is 4.2 mm at a normal load of 200 kPa whereas, at a normal load of 200 kPa + a shear load of 20 kPa, it is slightly reduced to 4.1 mm after 1 hour of testing.

Similarly, at a normal load of 200 kPa, the thickness of NC2 is 6.1 mm whereas, at a normal load of 200 kPa + a shear load of 20 kPa, it is slightly reduced to 6.0 mm after one hour of testing.

2.3 *Discussion of results*

Products thicknesses measured previously have been expressed as deformations using the following relationship :

$$D = \frac{T_{g0} - T_{gx}}{T_{g0}} x100 \qquad (3)$$

where D is a percentage of deformation , T_{g0} is the initial thickness (mm) and T_{gx} is the final thickness after x hours of testing (mm).

In this form, it was possible to compare the results thanks to graphs such as figure 5 for a load of 200 kPa.

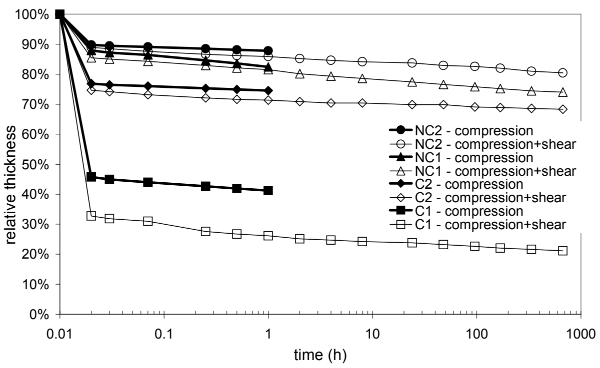

Figure 5 Comparison of creep curves at 200 kPa

We also extracted from these results the values of the percentage of deformation after 1 hour, as given in table 2.

Table 2 Products deformations (thickness decrease)

Product	Deformations (%) after compressive creep at 1hour			Deformations (%) after compressive + shearing creep at 1hour		
Load kPa	50	100	200	50	100	200
C 1	33.2	48.5	58.8	61.2	68.7	73.8
C 2	13.4	19.2	25.6	17.7	23.8	28.6
NC 1	5.5	9.3	17.6	9.3	15.4	18.5
NC 2	5.9	8.2	12.2	7.5	11.1	14.1

C1 and C2 are obviously the most compressible products with deformation percentages higher than 50% for C1 and more than 25% for C2 under a normal compressive load of 200 kPa. The products NC1 and NC2 are far less compressible with a deformation percentage at 200 kPa under a normal compressive load of 18 and 12% respectively.

When a combination of normal compressive and shear loadings is applied, it can be seen that the deformation of product C1 increases up to 73.8% whereas the products C2, NC1 and NC2 are not subjected to any substantial increase in their deformation percentage.

These 4 products have highly variable deformation reactions when subjected to loads. The most compressible product C1 creeps more with the shear effect, although its geospacer has the most homogeneous structure.

3 LONG TERM WATER FLOW CAPACITY

3.1 *Methodology*

In order to estimate the long-term water flow capacity of the tested geocomposite, we worked in three different steps :

- we extracted from figures 1 to 4, derived from creep tests, data couples (time t, thickness T_g) ;
- from figure 10, also derived from the creep test results, we determined the stress σ required to obtain thickness T_g in a flow capacity cell after 2 minutes rather than after a time t ;
- we transferred this stress σ onto figures 6 to 9. We were then able to deduce the corresponding flow capacity Q. On completing these procedures, we obtained a couple (flow capacity Q, time t).

The third step data were obtained during the second experimental phase : the flow capacity of each product was measured in several configurations : variable stresses, variable stress application time (2 minutes according to EN ISO 12958 standard and 1 hour) between different types of support (between steel plates and foam layers). On the contrary, the hydraulic gradient was always set equal to 1.

3.2 *Water flow capacity function of strain*

The experimental device used is conform to the EN ISO 12958 standard.

All the geocomposites were submitted to four stresses : 50 kPa, 100 kPa, 200 kPa and more than 300 kPa ; these loads were applied on the product set between 2 steel plates and 2 foam layers. For each load and each type of support, a new sample was used. Therefore, each sample was measured twice for each load and each type of support : initial flow measurement (according to standard) then measurement of the flow 1 hour after the load application.

The water flow capacity (according to the standard) function of the load, has been plotted on figures 6 to 9.

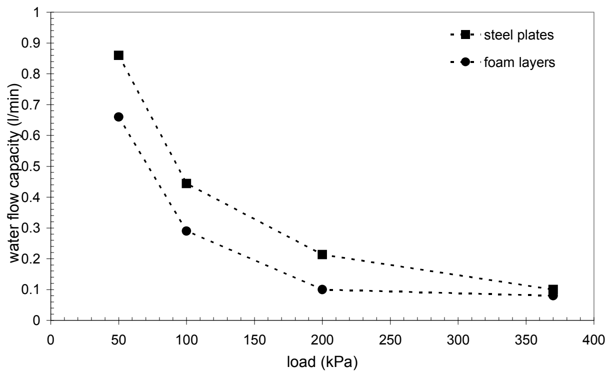

Figure 6 Product C1 : relation between flow capacity and load

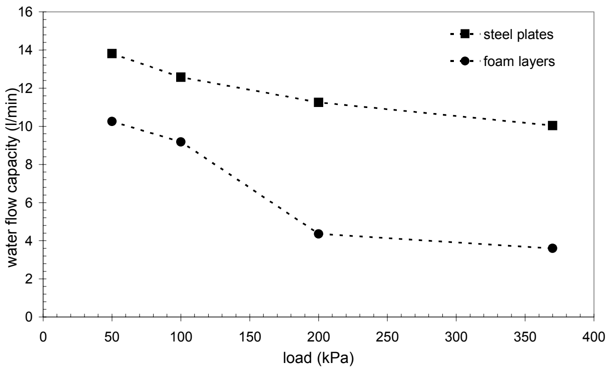

Figure 7 Product C2 : relation between flow capacity and load

These figures 6 to 9 reveal that the flow capacity :

- decreases when the applied stress increases
- is lower for the case between two foam layers than for the case between two steel plates.

For a compressible product (figure 6), the decrease in flow capacity between the two types of support is comparable.

For incompressible or semi-compressible products (figures 7 to 9), whereas the decrease in flow capacity is almost linear between two steel plates, between two foam layers, the decrease always represents a big step. This step is to be due to the inter-penetration of the foam material into the structure which is barely compressible.

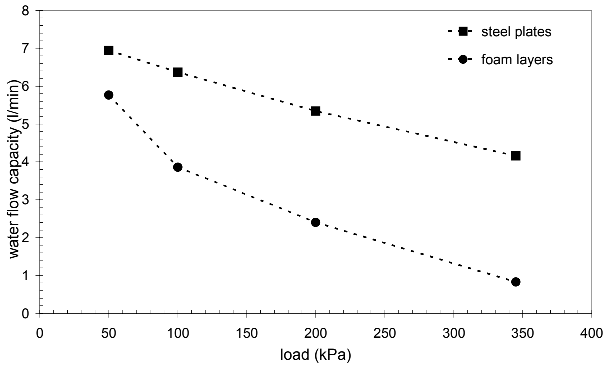

Figure 8 Product NC1 : relation between flow capacity and load

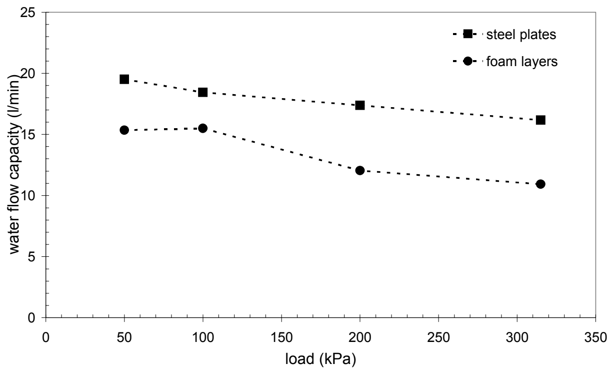

Figure 9 Product NC2 : relation between flow capacity and load

3.3 *Thickness, the way to get long term predictions*

In order to validate this approach, for each product and each load, the following flow capacity values Q have been checked. They correspond to :

- the direct measurement of Q after application of the stress for 1 hour
- the calculation of Q after 1 hour.

To evaluate the flow capacity after 1 hour, the thickness of the sample is extracted after 1 hour of compressive creep as explained in part 2.2, then the stress to which this thickness corresponds was determined, after the application of this stress during 2 minutes (figure 10).

Finally, from the graphs flow capacity function of stress (figure 6 to 9), the flow capacity corresponding to this stress is obtained. Results are presented in Table 3.

Table 3 Flow capacity ($l.min^{-1}$) after 1h at 50 kPa : Q_m = Q measured, Q_c = Q calculated

Products	Steel plates		Foam layers	
	Q_m	Q_c	Q_m	Q_c
C 1	0.7	0.7	0.6	0.5
C 2	13.6	13.5	9.2	10.0
NC 1	6.8	6.8	5.4	5.3
NC 2	19.2	19.1	13.7	15.4

It can be seen that the long-term approximation, using the variations in thickness as a basis, gives results that are in good agreement with the experimental measurements.

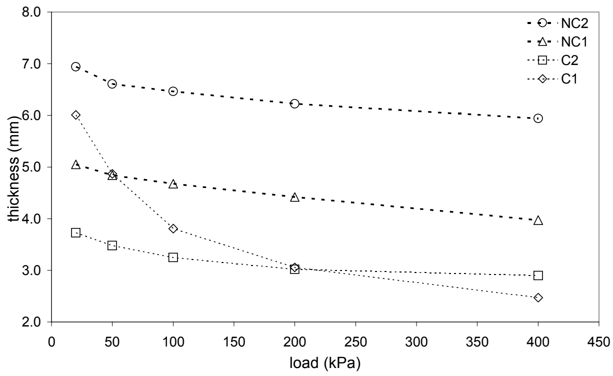

Figure 10 Product thickness after 2 min of creep

Our approach having been validated for one hour, it is assumed to be valid for longer periods of time. Moreover, the final results confirm this hypothesis as they match well with the values given in the literature concerning geospacers of the geogrid type.

3.3.1 *Relation between the water flow capacity and the thickness*

The flow capacity of the geogrids being proportional to their thickness, this relationship was to be checked for the tested geocomposites.

For each product was plotted the calculated flow capacity referred to the corresponding thickness, derived from the creep tests, function of the logarithm of time.

The data obtained between two foam layers were plotted in figures 11 to 14. The best fitting curves have been also plotted, with their correlation coefficient.

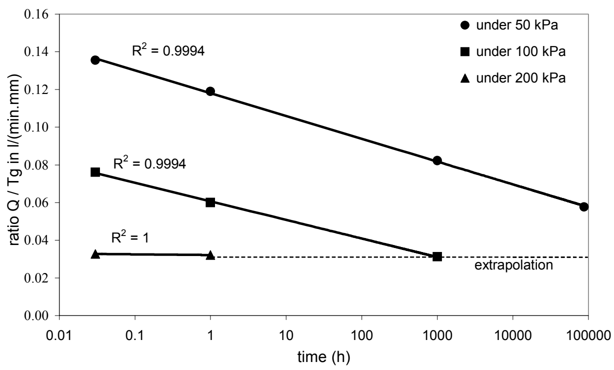

Figure 11 Product C1 : Evolution of the ratio Q to T_g

These graphs show that whatever the type of product, the ratio of the flow capacity to thickness varies almost linearly according to time, in the mechanical load tested.

Indeed, in figure 11 (product C1), the straight lines are parallel to one another whatever the applied stress is (or types of support), except in the case of the 200 kPa applied between two foam layers. This last straight line is almost horizontal : for C1, the flow capacity to thickness ratio cannot be lower, in theory, than 0.03 $l.min^{-1}.mm^{-1}$. Therefore, the curves have been extrapolated in such a way that the ratio does not decrease more than 0.03 $l.min^{-1}.mm^{-1}$.

The product NC1 (figure 13) is a similar case. However, the asymptotic value was not reached. Accordingly, for the extrapolation of the straight lines, the optimistic hypothesis that the last point obtained corresponds to this limit value has been considered: the straight lines were therefore extrapolated such as not decrease under 0.3 $l.min^{-1}.mm^{-1}$.

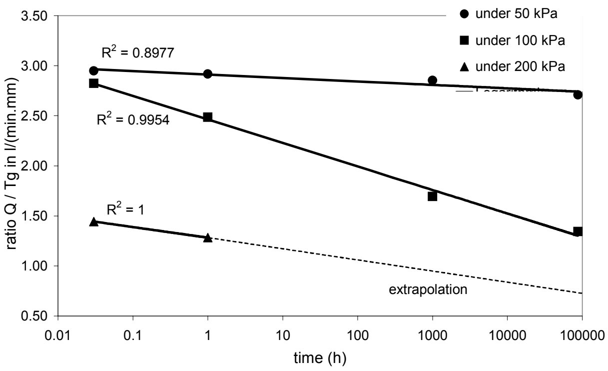

Figure 12 Product C2 : Evolution of the ratio Q to T_g

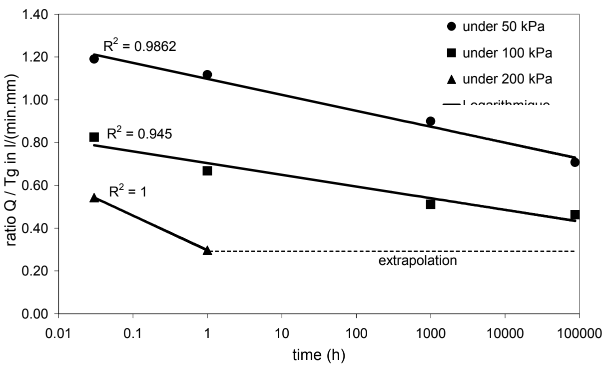

Figure 13 Product NC1 : Evolution of the ratio Q to T_g

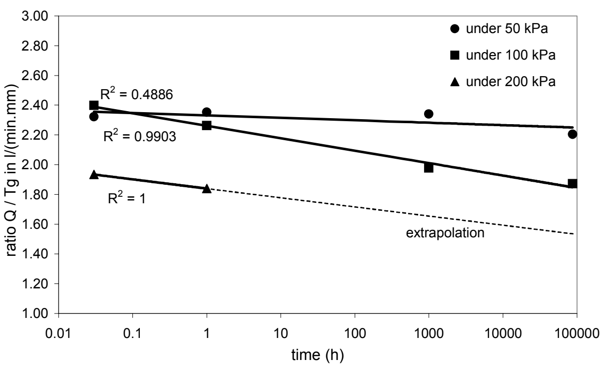

Figure 14 Product NC2 : Evolution of the ratio Q to T_g

Although the evolution of this ratio appears to be of interest, its value seems to be related only to the geospacer type : the values obtained ($l.min^{-1}.mm^{-1}$) are very different :

- from 0.03 to 0.18 for C1
- from 0.76 to 3.97 for C2
- from 0.30 to 1.43 for NC1
- from 1.55 to 2.95 for NC2

3.3.2 *Long term water flow capacity*

Figures 11 to 14 indicate the variations in the flow capacity with respect to the thickness as a function of time. Moreover, the evolution of thickness according to time is also known by the creep tests. The value of the long-term flow capacity has been calculated simply from these values.

Tables 4 to 7 refer to the value of the flow capacity measured according to the EN ISO 12958 standard (Q_i) and the approach to the long-term flow capacity as calculated (in this case, the calculation was made for the duration of 10 years (Q_f)).

There is obviously a difference in the behaviour of compressible products and incompressible products, or semi-compressible ones. In fact, for the former, the initial flow capacity decreases more or less within the same proportions between two types of support. On the contrary, for the last ones, the time-dependent flow capacity decreases far more between foam layers than between steel plates.

Table 4 Flow capacity of C1 after 10 years

Support		Steel plates			Foam layers		
Normal load	kPa	50	100	200	50	100	200
Q_i	l/min	0.86	0.44	0.21	0.66	0.29	0.1
Q_f (10 yrs)	l/min	0.34	0.07	0.06	0.2	0.07	0.06
Q_f / Q_i (%)		40%	16%	29%	30%	24%	60%

Table 5 Flow capacity of C2 after 10 years

Support		Steel plates			Foam layers		
Normal load	kPa	50	100	200	50	100	200
Q_i	l/min	13.81	12.57	11.25	10.26	9.18	4.36
Q_f (10 ans)	l/min	12.45	10.64	7.42	8.75	3.99	2.05
Q_f / Q_i(%)		90%	85%	66%	85%	43%	47%

Table 6 Flow capacity of NC1 after 10 years

Support		Steel plates			Foam layers		
Normal load	kPa	50	100	200	50	100	200
Q_i	l/min	6.94	6.37	5.34	5.76	3.86	2.40
Q_f (10 ans)	l/min	6.22	5.05	2.11	3.28	2.01	1.02
Q_f / Q_i(%)		90%	79%	40%	57%	52%	42%

Table 7 Flow capacity of NC2 after 10 years

Support		Steel plates			Foam layers		
Normal load	kPa	50	100	200	50	100	200
Q_i	l/min	19.52	18.45	17.37	15.35	15.50	12.05
Q_f (10 ans)	l/min	17.99	16.80	13.83	14.02	11.51	8.90
Q_f / Q_i(%)		92%	91%	80%	91%	74%	74%

For the compressible product, the time-dependent flow capacity decrease is only due to the creep phenomenon. Conversely, for the semi-compressible or incompressible product, in addition to the creep, the penetration of the foam material into the structure increases in time.

Furthermore, one remarkable value is revealed in table 4 : the flow capacity at 200 kPa and at 10 years is equal to 60% of the flow capacity measured according to the standard. This very high value can be explained easily by the compressible nature of the product. 200 kPa is a relatively high stress and the thickness reduction due to creep is low compared to the instantaneous decrease in thickness.

4 WHAT SAFETY FACTORS ARE TO BE CHOSEN ?

The flow capacity of a geocomposite is time-dependent. To predict for this loss in performance, a safety coefficient is applied to the announced value, according to the standard. This safety coefficient is in fact the product of partial safety coefficients (Koerner, 1998). The 4 main factors to be taken into consideration are :

- creep of the draining core (RF_{CR})
- intrusion of the geotextile in the draining core related to time deformations of the geotextile (RF_{IN})
- chemical clogging of the draining core (RF_{CC})

- biological clogging of the draining core (RF_{BC}).

Thus, we can calculate the long-term flow capacity in the soil (Q_{LTIS}) as a function of the measured flow capacity (Q_m) using equation (4).

$$Q_{LTIS} = \frac{Q_m}{RF_{CR} \, x RF_{IN} \, x RF_{CC} \, x RF_{BC}} \tag{4}$$

In the literature, there are ranges of variation of these reduction factors for products having a geogrid as a draining core according to the type of application to be designed. Accordingly, the reduction factor RF_{CR} is often given as included between 1.1 and 2.0 (Koerner 1998) depending on the applications (for geogrids).

Considering the results obtained in the tables 2 to 5 we are able to give a range of variation for the four tested products. Only the results between foam layers will be referred to because they are the most representative of the in situ conditions (soil, waste, etc).

4.1 *Product C1*

Its geospacer is a geotextile. We obtain a reduction factor range included between 3.3 and 4.2 for low to medium stresses. This is the only one of the tested product whose reduction factor for high stresses is really lower than for lower stresses , with a value of 1.7.

4.2 *Product C2*

Its geospacer is made of a random network of monofilaments. The range of variation of RF_{CR} is included between 1.2 and 2.3. The higher the stress applied to the product, the higher the reduction factor. Its semi-compressible nature is also found in the reduction factors : for high stresses, RF_{CR} is slightly less than for medium stresses (2.1 for 2.3).

4.3 *Product NC1*

Its geospacer is a geogrid. The variation range of RF_{CR} is included between 1.7 and 2.4. The higher the strain applied to the product, the higher the reduction factor. This range is in good agreement with the values that are commonly given in literature, although slightly higher.

4.4 *Product NC2*

Its geospacer is a symmetrical thermoformed sheet. The variation range of RF_{CR} is included between 1.1 and 1.4. The higher the strain applied to the product, the higher the reduction factor.

5 CONCLUSION

The EN 1897 standard doesn‘t recommend the compressive+shear loadings test except for products that are sensitive to shear. To be exhaustive, the 4 geocomposites of the study were tested to creep both for single compressive and for compressive+shear loadings.

The results show that shear load has an immediate effect on the thickness of all the products. For instance, the presumably least sensitive product to shear (geotextile geospacer) is in fact the most sensitive of all the products tested : it looses between 15% and 30% more of its thickness compared to a single compressive creep test. Therefore, all the products should be systematically subjected to a creep test including a shear load.

Furthermore, we demonstrated that the flow capacity is closely related to the thickness. It is accepted that the main cause of time-dependent decrease in flow capacity is creep phenomenon. The method presented in this work, based on time-dependent thickness of a product, and therefore knowledge of its thickness in the short and long-term, makes it possible to predict its flow capacity in the long-term as a function of its short-term flow capacity.

From these results, reduction factors related to the creep are proposed to be applied to the tested products in order to take into account the effect of creep in design. The values are comparable to those mentioned in the literature in the case of incompressible and semi-compressible product : we obtain a range included between 1.1 and 2.5 compared with the 1.1 and 2.0 that is commonly assumed. But these values do poorly apply to the compressible product as the values obtained are twice as high.

We have studied the long-term flow capacity in relation to the long-term thickness of products essentially solicited by a single compression. Taking into consideration the shear effect on the thickness, highlighted in the first part of the study, it would be worth developing an experimental device to measure the flow capacity of a product also submitted to shear. Indeed, shear can occur at 2 levels regarding the flow capacity results : in addition to a decrease in thickness, there may be a change in the interconnection between voids, thus modifying the hydraulic conductivity and the flow capacity.

6 ACKNOWLEDGEMENTS

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