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Mechanical Behavior of Geosynthetics vs. the Combining Effect of Aging, Temperature, and Internal Structure

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Abstract**—**Geosynthetic mechanical behavior vs temperature or vs aging has been widely studied independently during the last years, both in laboratory and in outdoor conditions. This paper studies this behavior deeper, considering that geosynthetics have to perform adequately at different outdoor temperatures once they have been subjected to a certain degree of aging, and also considering the different geosynthetic structures made of the same material. This combining effect has been not considered so far and it is important to ensure the performance of geosynthetics, especially where high temperatures are expected. In order to fill this gap six commercial geosynthetics with different internal structures made of polypropylene (PP), high density polyethylene (HDPE), bitumen and polyvinyl chloride (PVC), or even a combination of some of them, have been mechanically tested at mild temperature (20 ºC or 23 ºC) and at warm temperature (45 ºC) before and after specific exposition to air at standardized high temperature in order to simulate 25 years of aging due to oxidation. Besides, for 45 ºC tests, a heating system during test for high deformable specimens is proposed. The influence of the combining effect of aging, structure and temperature in the product behavior has been analyzed and discussed, concluding that internal structure is more influential than aging in the mechanical behavior of a geosynthetic versus temperature.

Keywords**—**Aging, geosynthetics, internal structure, temperature.

I. INTRODUCTION AND BACKGROUND

THE bibliography on the behavior of different geosynthetics or different materials used for manufacturing geosynthetics vs environmental agents is quite extensive. The studies of geosynthetics vs temperature, like the ones in [1]-[6], and geosynthetics vs oxidation, like the ones in [7]-[13], are particularly numerous. Special interesting topics discussed by those papers are the following:

- The combined effects of various environmental agents on the geosynthetics, e.g., [14], which evaluated the coupling effect of oxygen pressure and temperature on geosynthetic aging.
- The simulation of the effect of all the environmental agents that affect the geosynthetics at the same time during some critical moments, like installation, e.g., [15], which evaluates the effect of all the damaging agents during the installation of geosynthetics in asphalt roads, and
- The evaluation of the long-term performance of geosynthetics installed in actual civil works at atmospheric conditions or under water or different soils during decades, studied, e.g., [13] and [16]-[19].

All these papers contain important data to be considered in long term design of geosynthetics. But they also contain some gaps that could promote mistakes in specific design cases. The three more important forgotten additional points that must be considered in the behavior of geosynthetics vs temperature, aging and other simultaneous factors are the following ones:

- All the cited papers have assumed that geosynthetics have the same behavior vs temperature before and after oxidation aging. That statement should be demonstrated, even if oxidation exposition is not long enough to produce the first changes in mechanical behavior of geosynthetics.
- All the cited papers have not studied the influence of the different internal structures of those geosynthetics in durability. Geosynthetics made of the same materials can be very different due to their internal structure (net, smooth membrane, structured membrane, or a combination of them, as shown in Fig. 1), which could cause different behavior vs temperature or aging.
- Related with the previous point, nowadays many geosynthetics are made of a combination of materials. All the cited papers studied pure material behavior except [10], who studied a geosynthetic clay liner. At least the most common material combinations and possible interactions between them and with environmental agents should be considered in order to study their interactions, especially when different structures of the same raw materials are combined.

The detailed study of the synergy of these three factors (temperature, aging and internal structure) is important in the design of civil utilities where geosynthetics play an important or even an essential role during many years, much more where those geosynthetics are exposed to aggressive environmental agents, especially sunlight and oxygen.

The mentioned study will also produce useful data for geosynthetic modelling and design, which will give a better prediction of the geosynthetic performance after 10, 25 or more years of service in civil works.

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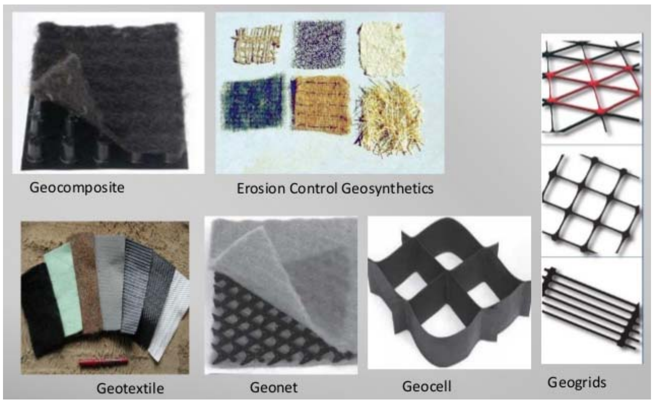


Fig. 1 Different internal structures of geosynthetics; extracted from [20]

In order to start covering the current gap in the state of the art of the combined influence of internal structure and oxidation in the mechanical behavior of geosynthetics at different temperatures, a battery of tests on 6 different geosynthetics made of four different materials and some of their combinations, performed at two different temperatures (room temperature and 45 ºC) and at two different oxidation conditions (as received conditions and at an oxidation degree equivalent to 25 years of outdoor aging), were planned.

The initial hypothesis is that the mechanical behavior of geosynthetics at different temperatures is affected by its oxidation degree and/or its internal structure, because:

- The oxidation degree can change the chemical and physical properties of the polymer. That is, the mechanical behavior of geosynthetics changes with increasing temperature in a different way when the oxidation degree is different.
- Changes in the internal structure of a geosynthetic can affect the mechanical behavior of such geosynthetic versus temperature. Examples of this could be:
  - o geosynthetics made of the same material, but with different internal structures (geonet, smooth geomembrane, structured geomembrane, woven geotextiles, non-woven geotextiles, etc.)
  - o combination of different raw materials in the same geosynthetics.
  - o specimens of different width from the same geosynthetic, because a lot of geosynthetic structures are in blocks, so different specimen width implies different local conditions that could behave differently versus temperature.
  - o short thermal treatments which can create local critical points whose behavior at different temperatures is different than the rest of the material.

As some of these geosynthetics have a very high deformability, usually the weathering chambers which are used for these tests are very limited to be employed with some geosynthetics, so this paper also proposes a method to get high temperatures to carry out mechanical tests on very deformable geosynthetics, based on radiation instead of convection.

II. MATERIALS, METHODOLOGY AND EXPERIMENTAL EQUIPMENT

Table I and Fig. 2 indicate the geosynthetic materials which were used for performing the tests and their internal structures. The raw materials used for the manufacturing of those geosynthetics are also indicated in Table I. The materials were selected due to their extended use in long life civil works, especially in new applications as sustainable urban design systems, green roofs, landfills, ponds, etc.

Tests were performed in two phases. The first phase included tensile tests of not oxidized samples at mild temperature (20 ºC or 23 ºC) and high temperature (45 ºC). This interval is very common in geosynthetic applications and, although there are not any important thermodynamical changes in the plastics in that range, it should be studied before analyzing other wider temperature ranges with more thermodynamical transitions, but whose temperatures are less realistic.

Due to the different nature of each material, the tensile tests are usually performed following a different standard for each one. Table II indicates the different standard followed for each material, which are the most used standards in industry. The size of the corresponding specimens, which depends on the chosen standard and the typology of testing machines, is also indicated.

TABLE I
SUMMARY OF THE MATERIALS USED IN THE RESEARCH

Material number	Description	Raw material	Structure
1	Geotextile 500 g/m^2	PP	White needle punched non-woven
2	Geodrain (geonet)	HDPE geonet + 2 PP geotextiles	A 5 mm thick polyethylene geonet placed between two 130 g/m^2 PP geotextiles
3	Geodrain (cavity)	HDPE membrane + PP geotextile	A 10 mm thick polyethylene cavity membrane stuck to a 130 g/m^2 PP geotextile
4	PVC geomembrane	PVC	2 mm thick PVC geomembrane
5	HDPE geomembrane	HDPE	2 mm thick HDPE geomembrane
6	Bituminous geosynthetic barrier	Polyester shell + elastomer modified bitumen + LDPE not adherent membrane	A polyester shell between two elastomer modified bitumen layers, protected by two LDPE not adherent layers

Phase 2 consisted on developing a specific oxidation test on each material that simulated an aging of 25 years and the evaluation of the remaining strength and strain after the exposition. The corresponding standard, the aging conditions and the time for each exposition are summarized in Table III. Those exposition times are indicated by each standard in order to simulate 25 years of service life. The scientific reasons for that time election, especially for geotextiles, are shown in [24].

The studied properties, remaining strength and remaining strain, were chosen as representatives of geosynthetic behavior for long time, although they are not always the main function of the selected geosynthetic in their most frequent applications, because they are usually studied in bibliography and they are basic for the overall geosynthetic perform. A geosynthetic which not mechanically resists will not correctly perform its main functions.

Fig. 2 Materials used for the experimental program

TABLE II
TENSILE TEST STANDARDS SPECIFICATION (PHASE 1)

Material	Standard	Specimen sizes (cm)
Geotextile 500 g/m^2	EN ISO 10319:2015 [21]	20x38
Geodrain (geonet)	EN ISO 10319:2015 [21]	20x38
Geodrain (geospacer)	EN ISO 10319:2015 [21]	20x38
PVC geomembrane	EN ISO 527-3:1996 and AC:2002 [22]	Type 5
HDPE geomembrane	EN ISO 527-3:1996 and AC:2002 [22]	Type 5
Bituminous geosynthetic barrier	EN ISO 12311-1:2013 [23]	Type 5

TABLE III
OXIDATION TEST SPECIFICATIONS EQUIVALENT TO 25 YEARS OF SERVICE LIFE (PHASE 2)

Material	Standard	T (ºC)	Specimen size (cm)	Time (days)
Geotextile 500 g/m^2	EN ISO 13438:2018[24]	110	5x30	28
Geodrain (geonet)	EN ISO 13438:2018[24]	100	5x30	56
Geodrain (cavity)	EN ISO 13438:2018[24]	100	5x30	56
PVC geomembrane	EN 14575:2007 [25]	80	Type 5	120
HDPE geomembrane	EN 14575:2007 [25]	85	Type 5	90
Bituminous geosynthetic barrier	EN 14575:2007 [25]	85	Type 5	90

Tensile tests of oxidized and control specimens were also performed at 20 ºC (or 23 ºC, depending on the tensile test standard, as indicated previously) and 45 ºC. Please, take into account that specimen size for geotextiles and geodrains in these tensile tests were 30x5 cm, as stated in [24].

Oxidation was chosen, instead of other aging mechanisms, like UV, hydrolysis or microbiological activity because it is suffered by all the geosynthetics during their service life, because the relation between exposition time and years of service life is clearer and because the exposition times are shorter than for other degradation mechanisms, especially UV and microbiological activity.

The bituminous barrier was considered a special case. It undergoes a short thermal treatment, even by flame exposition, during its installation. So, independently from the oxidation simulation, supplementary specimens were exposed only at a thermal treatment of 85 ºC during 24 hours applied in order to simulate thermal stresses that they can suffer during installation, whose influence in their mechanical resistance vs temperature behavior is not well known.

The ovens used for oxidation and thermal treatments during this test program were a JPSELECTA DIGITHEAT 80L for oxidation of geotextiles and an INDELAB IDL-FI-80 for oxidation of geosynthetic barriers, in order to not mix different products in the same oven. A static universal testing machine Zwick Z100 was used to perform all the tensile tests except for the bituminous material. For this particular material, specimens could be cut at the edge of the flat clamps according to previous experience in the laboratory. Therefore, it was decided to use a static Zwick Z250 machine with capstan clamps.

When tensile tests should be performed at mild temperature, a room with an air conditioning equipment was used to get the following conditions, indicated in the corresponding standards:

- 20 ºC ± 2 ºC and 65% ± 5% HR for the geotextile and geodrains, according to [21].
- 23 ºC ± 2 ºC and 50% ± 10% HR for the polymeric and bituminous barriers, according to [22] and [23]

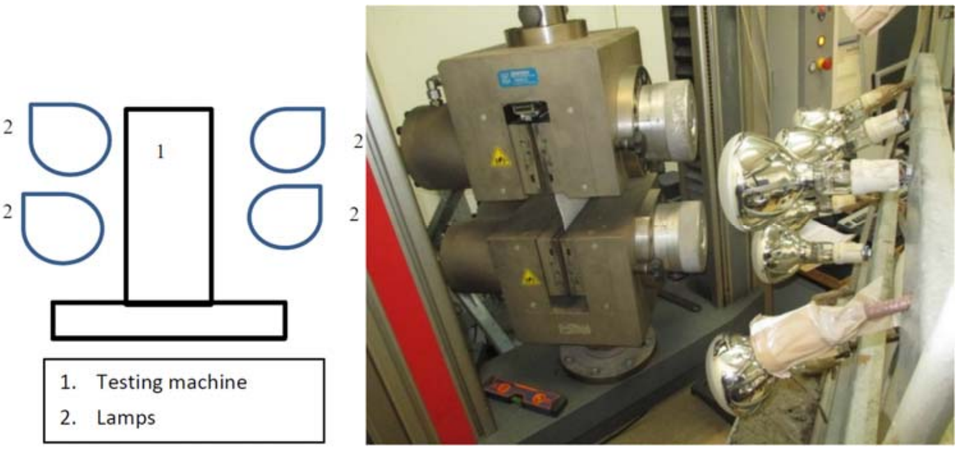
When tensile tests had to be performed at 45 ºC, as all these geosynthetics, especially geomembranes, could have a great deformation at breaking point, and there are not suitable weathering chambers with enough height. Therefore, a lamp heating system based on two panels at both sides of the tested specimen was used instead. The chosen lamp model was the OSRAM ULTRA-VITALUX™, with power of 300 W for each lamp and a size code E27/ES. They worked at a voltage of 230 V and they had a radiation mix which simulated the sun exposition. The temperature on the specimen was controlled by an infrared thermometer PCE-889A. The scheme and photograph of this experimental device used for tensile tests at 45 ºC are shown in Fig. 3. The needed time to reach 45 ºC was only about 5 minutes, so it was considered that damage was not produced to the geosynthetics due to UV exposition during the tensile tests. Temperature on the geosynthetics were measured with PCE non-contact infrared thermometer which scanned the sample approximately every 30 seconds. All the tests performed with this method had an experimental error in the obtained temperatures of +/-2 ºC, which was considered acceptable.

As explained before, after the performance of the tests, the obtained tensile and strain properties versus the test temperature were studied for all the geosynthetic samples before and after oxidation. After that, we evaluated if the obtained mechanic properties versus temperature relations changed due to some structural characteristics of the geosynthetics, as their internal structure, the specimen width, their raw materials, the combination of raw materials or different thermal treatments. To do so, a statistic treatment based on the design of experiments and response surfaces methodology was used. Their details are explained in next section.

III. DESIGN OF EXPERIMENTS AND RESPONSE SURFACES

MINITAB 17, a generic statistical software, was used to generate the DOE (design of experiments: combinations of input factors) and the response surfaces (also known as the regression models), in order to determine which studied factors were significant. A full factorial design with central composite, combining factors with different levels, was used for the mechanical properties vs test temperature study, the first part of the analysis. Linear terms and second order interactions were included in the response surface, a priori, to check which of these factors have a significant influence on each regression model:

- Response surfaces (also referred as dependent variables):
    - Residual strength: in order to be able to compare all results into a single regression model, values were averaged and normalized considering that no aging and mild temperature represents 100 % residual strength.



(a) (b)

Fig. 3 (a) Scheme; (b) photograph of the experimental equipment for tensile test of a geotextile at 45 ºC

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    - Residual strain: results were also averaged and normalized, considering that 100% was the value for residual strain obtained at mild temperature with no aging.
- Factors (also referred as independent variables):
    - Tensile test temperature (two levels): 1 (mild temperature: 20 ºC or 23 ºC, depending on each standard test procedure), 2 (high temperature: 45 ºC).
    - Oxidation time (two levels): 1 (0 years aging), 2 (25 years equivalent aging).
    - Materials (6 levels): 1 (geotextile), 2 (geodrain-geonet), 3 (geodrain-cavity), 4 (geomembrane-PVC), 5 (geomembrane-HDPE), 6 (geomembrane-bitumen-), as indicated in Table I.

After completing the first part of the statistical analysis, the following further correlations were studied in the second part of the analysis:

- Mechanical properties vs temperature for the two geodrains which have the same materials, but are made of different internal structures (materials 2 and 3), before and after aging. In this case the temperature is the first factor; aging is the second factor and the structure (with two levels, geonet and cavity) is the third factor.
- Mechanical properties vs temperature for the geotextile and both geodrains, when specimens with different width were tested. In this case the temperature is the first factor, the material (with three levels, geotextile, geonet and cavity) is the second factor, and the specimen width (with two levels, 5 cm and 20 cm) is the third factor.
- Finally, the mechanical properties vs temperature behavior only for the bituminous geosynthetic barrier were studied for specimens with and without a thermal treatment at 85 ºC during 24 hours, which simulates thermal stresses that this specific product can suffer during its installation and which can affect in a different way the two materials than compose the geosynthetic barrier. In this case, the test temperature is the first factor (with two levels, 23 ºC and 45 ºC); the materials that compose the bituminous barrier (polyester and bitumen) are the second factor and the thermal treatment is the third factor (with two levels: presence or absence).

The confidence interval considered was 95% (p-value of 0.05). All the results fulfilled a normal distribution and there was homogeneity of variances, so statistical correlations could be calculated. So, if R^2 values are high, Aprox. 1, which means that the correlation is correct, and if p-value is smaller than 0.05, our hypothesis is correct and the studied factor affects the mechanical behavior versus temperature for the considered geosynthetics.

IV. RESULTS AND DISCUSSION

A. Evaluation of Influence of Aging in Strength and Strain Behavior of Geosynthetics vs. Temperature

Table IV and graph in Fig. 4 gather the normalized strength and strain values obtained for each geosynthetic tested before and after aging and at the two different tensile test temperatures: mild (20 ºC or 23 ºC) and warm (45 ºC).

After the corresponding statistical analysis, correlation which evaluates the influence of each factor (temperature, aging and material) and its second order interactions on the behavior of the geotextile strength and strain were obtained. Results are summarized in Table V. In these table p-values for each factor and interaction are shown. The obtained p-values, higher than 0.05 for AB interaction, the issue mainly studied, indicate that the linear relation of geosynthetic mechanical behavior versus the temperature does not vary when different oxidation degrees are considered. Strain vs AB interaction correlation is not good and it cannot be used to predict strain values at different temperatures. But correlation strength vs AB interaction is good (R^2 is 0,99 and R^2(pred) is 0,84), and also in this case it can be observed that the p-value for AB interaction is much higher than 0.05, higher than p-value for other considered factors and even higher than other interactions, like AC.

TABLE V
P-VALUES FOR INTERACTION AB (TEMPERATURE, AGING) IN CORRELATIONS OF GEOTEXTILE STRENGTH AND STRAIN VS TEMPERATURE (A), AGING (B) AND MATERIAL (C)

Dependent variables	p-values					
	A	B	C	AB	AC	BC
Strength	0.000	0.001	0.001	0.410	0.008	0.001
Strain	0.369	0.808	0.899	0.353	0.791	0.932

So, the initial hypothesis was not confirmed; that is, the behavior of geosynthetics vs temperature is not affected by the oxidation degree of those geosynthetics. Geosynthetic behavior vs temperature is resilient to a level of aging that is equivalent to 25 years of service life. That is true even when the oxidation is advanced, as in the case of the non-woven geotextile. This mathematically quite clear conclusion experimentally confirms that geosynthetics are reliable for long time uses, as indicated by [1], [2] and [26] in their selected in-situ studies.

TABLE IV
AVERAGED AND NORMALIZED RESULTS OF STRENGTH AND STRAIN VS. TEMPERATURE, AGING AND MATERIAL

T (ºC)	Aging time (years)	Material	Relative strength (%)	Relative strain (%)
20	0	Geotextile	100.00	100.00
45	0		76.28	100.98
20	25		54.45	65.55
45	25		41.54	59.57
20	0	Geodrain (GEONET)	100.00	100.00
45	0		85.52	106.08
20	25		94.51	91.70
45	25		74.00	101.32
20	0	Geodrain (GEOSPACER)	100.00	100.00
45	0		90.66	101.05
20	25		94.71	86.04
45	25		90.60	89.74
23	0	Geomembrane (PVC)	100.00	100.00
45	0		99.61	70.85
23	25		100.06	14.97
45	25		99.71	183.83
23	0	Geomembrane (PEAD)	100.00	100.00
45	0		70.75	119.06
23	25		102.26	106.72
45	25		76.00	127.24
23	0	Geomembrane (BITUMEN)	100.00	100.00
45	0		92.67	98.35
23	25		102.56	108.69
45	25		94.76	110.32

B. Evaluation of Other Factors (Structure, Specimen Width, Thermal Treatment) in Geosynthetic Behavior vs. Temperature

As there is not actual influence of aging on the temperature behavior of any of the tested geosynthetics, other relations were studied from the obtained results in order to confirm or not the second hypothesis. Tables VI-VIII summarize the averaged and normalized results that were studied in this part of the analysis.

TABLE VI
AVERAGED AND NORMALIZED RESULTS OF STRENGTH AND STRAIN VS TEMPERATURE, AGING AND GEODRAIN STRUCTURES

T (ºC)	Aging time (years)	Material	Relative strength (%)	Relative strain (%)
20	0	Geodrain (GEONET)	100.00	100.00
45	0	Geodrain (GEONET)	85.52	106.08
20	25	Geodrain (GEONET)	94.51	91.70
45	25	Geodrain (GEONET)	74.00	101.32
20	0	Geodrain (GEOSPACER)	100.00	100.00
45	0	Geodrain (GEOSPACER)	90.66	101.05
20	25	Geodrain (GEOSPACER)	94.71	86.04
45	25	Geodrain (GEOSPACER)	90.60	89.74

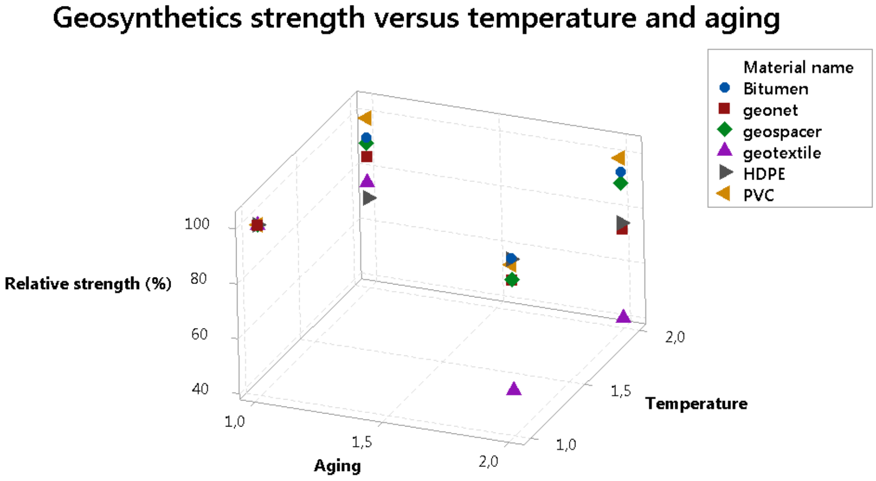
TABLE VII
AVERAGED AND NORMALIZED RESULTS OF STRENGTH AND STRAIN VS. TEMPERATURE, SPECIMEN WIDTH AND MATERIAL

T (ºC)	Specimen width (cm)	Material	Relative strength (%)	Relative strain (%)
20	5	Geotextile	26.19	114.69
45	5	Geotextile	19.98	115.82
20	20	Geotextile	100.00	100.00
45	20	Geotextile	74.82	124.89
20	5	Geodrain (GEONET)	24.78	112.92
45	5	Geodrain (GEONET)	21.19	119.79
20	20	Geodrain (GEONET)	100.00	100.00
45	20	Geodrain (GEONET)	72.61	99.13
20	5	Geodrain (GEOSPACER)	23.35	116.84
45	5	Geodrain (GEOSPACER)	19.34	117.65
20	20	Geodrain (GEOSPACER)	100.00	100.00
45	20	Geodrain (GEOSPACER)	72.88	109.98

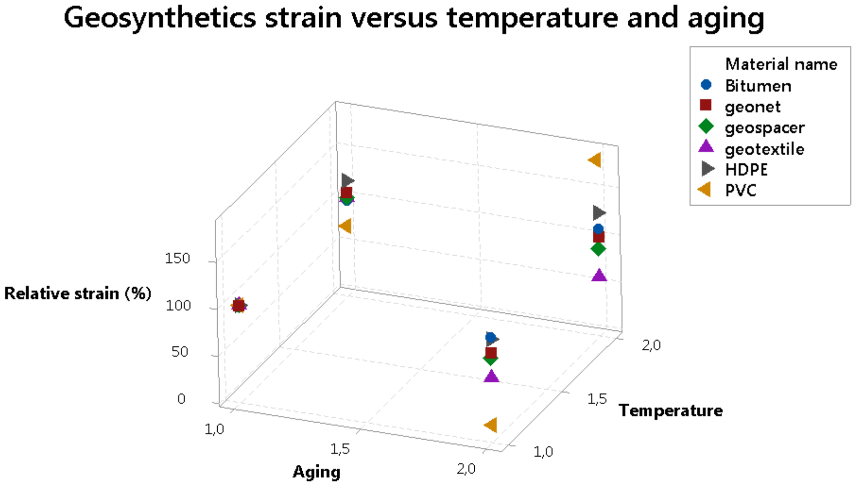
TABLE VIII
AVERAGED AND NORMALIZED RESULTS OF STRENGTH AND STRAIN VS. TEMPERATURE, PEAK NUMBER AND THERMAL TREATMENT FOR THE BITUMINOUS GEOMEMBRANE

T (ºC)	Peak number	Thermal treatment	Relative strength (%)	Relative strain (%)
23	1	85 ºC during 24 hours	100.38	80.15
45	1	85 ºC during 24 hours	79.71	75.49
23	1	None	100.00	100.00
45	1	None	88.10	94.77
23	2	85 ºC during 24 hours	102.91	75.63
45	2	85 ºC during 24 hours	69.60	55.64
23	2	None	100.00	100.00
45	2	None	80.15	73.58

First, the influence in geosynthetic behavior of the different structures of the two geodrains, made with the same materials, was studied. The statistical analysis was the one explained in the Subsection *A*, except for factor C which was called structure (because the materials are the same). This factor C had two levels (geonet and cavity). The results for p-values are shown in Table IX. It was found out that the structure does not have influence on the strength vs temperature behavior, but it could have some influence on strain vs temperature behavior and even on strain vs aging behavior.



(a)



(b)

Fig. 4 Average and normalized results for tests on all the geosynthetics before and after oxidation at 20 ºC and 45 ºC

TABLE IX
P-VALUES FOR INTERACTIONS AC (TEMPERATURE·STRUCTURE) AND BC (AGING·STRUCTURE) IN CORRELATIONS FROM TABLE VI

Dependent variables	p-values					
	A	B	C	AB	AC	BC
Strength	0.145	0.297	0.302	0.955	0.307	0.489
Strain	0.028	0.015	0.025	0.091	0.051	0.046

The second studied factor of possible influence on mechanical behavior of some geosynthetics vs temperature was the specimen width. This factor was studied for the geotextile and the two geodrains. As explained in the design of experiments section, factor A was temperature, factor B was material (with only three levels: geotextile, geonet and geodrain-cavity) and factor C was specimen width (with two levels: 5 cm and 20 cm); only not aged specimens were considered. In this case, the value 100 % for the normalized strength and strain is given to the values obtained for 20 ºC and 20 cm of specimen width. The results are shown in Table X. It can be verified that the specimen width clearly affects the strength vs temperature behavior of the studied geosynthetics.

Consequently, as pointed out in the Introduction Section, the fact that the specimen width affects the strength-temperature behavior of the geosynthetic implies that some local changes in the structure of a geosynthetic can affect its behavior vs temperature.

TABLE X
P-VALUES FOR INTERACTION AC (TEMPERATURE·SPECIMEN WIDTH) IN CORRELATIONS FROM TABLE VII

Dependent variables	p-values					
	A	B	C	AB	AC	BC
Strength	0.002	0.481	0.000	0.994	0.005	0.684
Strain	0.257	0.641	0.145	0.695	0.454	0.550

Finally, the third and last studied factor of possible influence on temperature behavior of some geosynthetics is the thermal treatment of geosynthetics. Many geosynthetics are submitted to high temperatures during short periods of time during their installation, for example during thermal bondings of two membranes. That short thermal treatment could affect their structure. In this case, some specimens of bituminous barrier were treated at 85 ºC for 24 hours and they were compared with other specimens which did not undergo that treatment. The statistical treatment, explained in the Design of Experiments Section, defined temperature as factor A, the relative peaks in the strength-strain graph, as defined in Fig, 5 (peak 1 corresponds to the polyester failure and peak 2 to the bitumen failure) was factor B, and factor C was the presence or absence of thermal treatment. The value of 100% was given to the specimens tested at 23 ºC without thermal treatment, for each relative peak. The results are shown in Table XI. It can be verified that the thermal treatment has significant influence on the change of the strain parameter vs temperature.

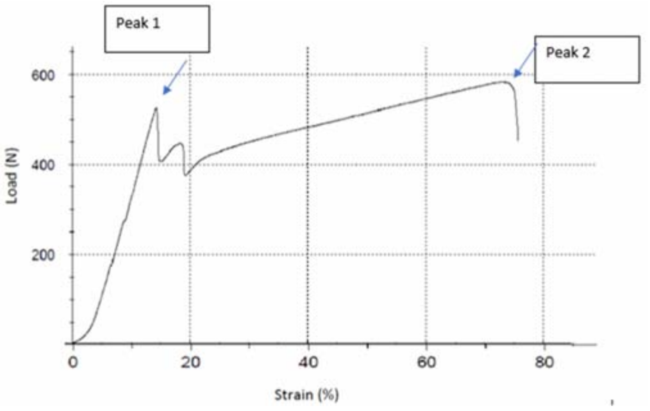


Fig. 5 An example of the graph obtained from the tensile test of a specimen of a bituminous geosynthetic barrier

TABLE XI
P-VALUES FOR INTERACTIONS AC (TEMPERATURE·THERMAL TREATMENT) IN CORRELATIONS FROM TABLE VIII

Dependent variables	p-values					
	A	B	C	AB	AC	BC
Strength	0.035	0.186	0.185	0.142	0.132	0.950
Strain	0.034	0.274	0.034	0.730	0.035	0.598

The relations between temperature behavior and structure or thermal treatment of the geosynthetics that have been obtained in this paper are not still as precise as required for design applications, but they are clear enough. So, it is worth dedicating more research efforts to determine them exactly.

After examining these results, it is clear that mechanical behavior of a geosynthetic vs temperature does not change during time due to aging effects, at least during 25 years of service life. This geosynthetic mechanical performing vs temperature could be affected by other factors which interact with the original raw material behavior, as the geosynthetic structural design and thermal treatment before or during installation. This fact, although maybe expected and known by many civil engineers, is not taken into account in order to perform a more precise design of geosynthetics, which is needed to improve much more their demonstrated capacity to work during long service lives. Research like the one in this paper is needed in order to develop more precise design methods to avoid the large uncertainty that sometimes are still related with the use of geosynthetics.

V. CONCLUSIONS

The discussion of the results allows to highlight two main conclusions:

- There is not any significant influence of 25 years equivalent aging of a geosynthetic when it is mechanically tested at different temperatures, even when the oxidation is advanced, as in the case of non-woven geotextiles. That is, the change of the mechanical behavior of different geosynthetics when the temperature changes during the tensile test seems to be resilient to oxidation processes along 25 years.
- The following factors, which are related with the internal structure and change in local conditions of geotextiles, have an influence on their mechanical behavior versus temperature:
  - The different structures of different geodrains which are made of the same materials.
  - The specimen width of the non-continuous geosynthetics.
  - Short thermal treatments on geosynthetics, like those applied during the installation of geosynthetics.

These conclusions need to be further confirmed and quantified with more experimental data, but they are solid enough to consider that the mentioned factors should be considered to get more precise geosynthetic designs.

Finally, this paper introduces with success the use of lamps which imitate sunlight to heat high deformable geosynthetics by radiation, not only using convection ovens, whose use is difficult when the strain at failure of the studied material is remarkably high.

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