Confined-accelerated Creep Tests on Geosynthetics

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ABSTRACT
The creep behavior of geosynthetics usually characterized by standard tests which present two main concerns: they are time-consuming and may not consider the possibly significant effect of soil confinement. Several approaches have been presented in the technical literature in order to address each of these aspects, but only independently. Recently, a new apparatus was developed in order to conduct confined-accelerated creep tests using geosynthetics and both concerns were addressed simultaneously. This paper presents a new set of creep tests conducted under different conditions with the new equipment. A biaxial geogrid and a nonwoven geotextile were used in these tests, which comprised creep rupture and creep deformation ones, both in in-isolation and in-soil conditions. The results highlight the importance of both using elevated temperatures to expedite the determination of geosynthetics creep behavior and studying the effect of soil confinement in both creep test types (creep rupture and creep deformations tests).

1. INTRODUCTION

The creep behavior of geosynthetics commonly plays an important role in the computation of the design tensile strength of these materials when used in reinforced soil structures. Among the reduction factors used to define this parameter, the one related to creep of geosynthetics usually presents the highest values (Koerner, 2005). The reduction factor due to creep behavior is quantified by conducting standard tests (ASTM D 5262), in which in-isolation specimens are subjected to a continuing and constant force while their elongation is measured. These tests are performed under controlled temperature and relative humidity conditions. In addition to the determination of the design tensile strength, creep strains obtained from such tests may be used to evaluate the reinforced soil structure behavior prior to its construction. Therefore, it can be noticed that the geosynthetics standard creep tests are used to define both the design strength and the behavior in such type of geotechnical structure.

Geosynthetics standard creep tests have been widely used to quantify the creep behavior of geosynthetics materials, mainly due to its simplicity. However, this type test presents two main concerns. Firstly, it is time-consuming, with test duration reaching 10,000 hours. Secondly, the configuration used in standard tests does not consider the possibly significant effect of soil-geosynthetic interaction (soil confinement). Together, these aspects may lead to expensive test sets and conservative results.

Geosynthetics creep response may be accelerated by conducting standard creep test at elevated temperatures (Bueno et al. 2005). These tests are commonly referred as accelerated creep tests. The creep strains at the reference temperature (e.g. room temperature) are inferred by calculations based on time temperature superposition techniques and their results. Therefore, several in-isolation accelerated creep tests with different specimens must be performed at the same load, yet at different temperatures. This set of test results is used to compose a creep master curve, which represents the creep response of the geosynthetic at the reference temperature and reaches greater times than those used in each accelerated test. This method is very well established in the technical literature. Several studies have been reported using accelerated creep tests to define geosynthetics creep response (Jeon et al., 2002; Zornberg et al., 2004; Bueno et al., 2005; Jones and Clark, 2007; Tong et al., 2009; Yeo et al., 2009). In addition, Thornton et al. (1998) proposes a new approach for evaluating tensile creep behavior of geosynthetics by means of accelerated tests, which is described by ASTM D 6992. This new method is based on increasing the test temperature in stages, which reduces the implications of material variability in the test results.

Soil confinement may have a great influence on the stress-strain behavior of geosynthetics. This aspect is usually referred to different mechanisms that restrict fibers and yarns relative movements (Elias et al., 1998). Thus, it is expected that the soil confinement effect on stress-strain behavior of geosynthetics is more substantial in geosynthetic materials manufactured with elements (fibers and yarns) which are free to move or adjust their position within the geosynthetic matrix (e.g. nonwoven geotextiles). Accordingly, geogrids are commonly considered as an example of the geosynthetic materials which stress-strain behavior is not affected by soil confinement. The geogrid ribs are not allowed to change position while loaded due to the strength of their connections. In addition, woven geotextile are generally considered as intermediary materials in this regard. Despite these stress-strain behavior pattern is frequently reported in the technical

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literature, Elias et al. (1998) emphasize the importance of defining the influence of soil confinement concerning this aspect in every geosynthetic prior to real structure construction. This suggestion was based on test results in which the stress-strain behavior of a woven geotextile was dependent on soil confinement. Conversely, Boyle et al. (1996) reported a set of tests in which samples of woven geotextiles stress-strain behavior was not affected by soil confinement.

The soil-geosynthetic interaction may restrain creep strains while a continuing and constant load is applied to a geosynthetic specimen. In fact, the creep behavior of geosynthetics is commonly reported to be similar to that mentioned for their stress-strain behavior. This aspect is related to the second concern of standard creep tests (lack of soil confinement). Creep tests conducted in special chambers with in-soil specimens are more likely to address this concern. This approach was pioneered by McGown et al. (1982) and several recent studies in which other types of equipment were used are reported in the technical literature (Costa, 2004; Mendes et al., 2007; Ding, et al., 2009; Kamiji et al., 2009). Although there are a vast number of available publications, a standard approach to perform in-soil creep tests was not established so far.

Confined creep tests using geosynthetics are commonly reported using three different loading systems. Firstly, as presented by McGown et al. (1982), the specimen is loaded by means of clamps attached to a portion of the specimen located outside the testing chamber, while normal stresses are applied. The second type of loading system applies a vertical stress over the confining soil and, at the same time, the testing chamber side walls are allowed to move laterally. This produces a soil horizontal strain due to the vertical stress application. This type of equipment was used by Costa (2004) and Kamiji et al. (2009). A third type of confined creep test on geosynthetics has also been reported. This includes tests conducted with pullout testing equipment in which the load is maintained constant during the pullout test, while normal stresses are applied (Elias et al., 1998).

Each type of creep tests loading systems represents a different location of the geosynthetic material inside the reinforced soil mass. The first one, in which the specimen is loaded by means of clamps (external loading), may be used to characterize the creep behavior of the portion located in the passive zone, where insignificant soil mass movement is noticed. The portion in the active zone of the reinforced soil mass is more likely to be represented by means of creep tests in which the soil is allowed to deform laterally during the test and the load is transmitted by soil-geosynthetic interaction. Finally, creep tests using pullout testing equipment may represent the region at the end of the geosynthetic reinforcement inside the passive zone. A similar description was reported by Palmeira and Milligan (1989) regarding the mechanisms of interaction in reinforced soil structures.

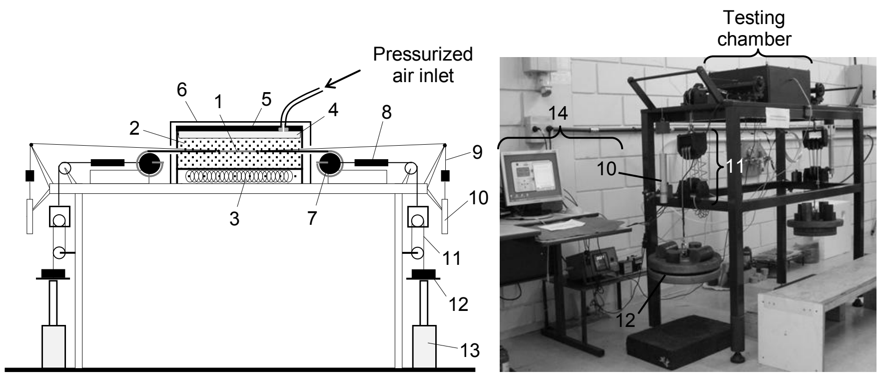
Both elevated test temperature and in-soil specimen approaches have been successfully reported in the technical literature, but only independently. Regarding this, França (2012) fully presents a new device capable of conducting simultaneously confined and accelerated creep tests. This equipment was developed in the Laboratory of Geosynthetics of the School of Engineering of the University of São Paulo at São Carlos and was firstly presented in França and Bueno (2010). Further descriptions are presented in França et al. (2011) and França and Bueno (2011). Improvements have been added to this new equipment concerning the loading system. In addition, further tests were performed with both a biaxial polyester geogrid and a polyester nonwoven geotextile. This paper presents a brief description of the new device and the improvement provided to its loading system. Moreover, the results of additional tests are presented and discussed.

2. NEW CREEP TESTING EQUIPMENT

The main objective of the new creep testing equipment development was to simultaneously address both main concerns of conventional creep tests. Therefore, it comprises several systems which are responsible for confining the specimen in soil, elevate the temperature, apply the continuing and constant load, measure specimen elongation and acquire data from the tests. Figure 1 presents a general view of the new equipment with the main components.

The testing procedure consists of positioning a 200 mm wide geosynthetic specimen (1100 mm long) into the upper portion of the testing chamber (400 mm wide, 400 mm long and 200 mm high). This part of the chamber is filled with soil in order to reproduce soil-geosynthetic interaction. A thermocouple is installed in this procedure to measure the temperature nearby the specimen, which is considered as the test temperature. The lower portion houses three electrical resistances and a second thermocouple and is also filled with soil to improve heat transfer to the upper portion. The thermocouple in the lower portion controls the temperature of the electrical resistances. A pressurized air bag is placed over the top of the soil fill and is used to apply normal stresses up to 150 kPa. The chamber lid is attached to its walls and provides the reaction necessary to reach such values. Finally, a polystyrene cover surrounds the testing chamber to prevent heat loss during elevation of test temperature.

Both side walls of the upper portion of the testing chamber are provided with apertures wide enough (5 mm) to allow the specimens to reach the outer roller grips. The grips are connected to dead weights by steel cables. Thus, dead weights are used to apply the continuing and constant load to specimens during creep tests. Besides, a set of pulleys is used to multiply to load that reaches the specimen by a factor approximately equal to 5.7. The loading system also comprises two load cells to register the load in each side of the specimens.



1 – Geosynthetic specimen
2 – Upper portion of the testing chamber (confining medium and specimen)
3 – Lower portion of the testing chamber (heating system)
4 – Pressurized air bag
5 – Testing chamber lid
6 – Expanded polystyrene cover
7 – Roller grip
8 – Load cell
9 – Stainless steel wire
10 – Displacement transducer
11 – Pulley set
12 – Dead weight
13 – Hydraulic jack
14 – Data acquisition system

Figure 1. Main elements of the new creep testing equipment (França et al., 2012).

Two hydraulic jacks were used in the first version of the new equipment to apply creep load in a constant, smooth, proper way. Hence, the loading process should be performed by two operators at the same time. As a result, some tests presented different load rates in each side of the specimen. Concerning this, a new loading system was implemented to the equipment developed by França (2012). It consists of a steel beam that simultaneously supports the dead weight from both sides of the equipment. Then, an electrical rotor controls the downward movement of the beam, providing a smooth and homogenous loading rate in both sides of the specimen. Loading rate can be programed by means of an automated controller. Figure 2a illustrates the new apparatus implemented to the loading system of the new creep testing equipment, while Figure 2b presents the load level during the first five minutes of a confined-accelerated creep test performed with a nonwoven geotextile loaded to 70% of its ultimate tensile strength (UTS). This test was conducted at 36.2°C and with normal stress equal to 50 kPa.

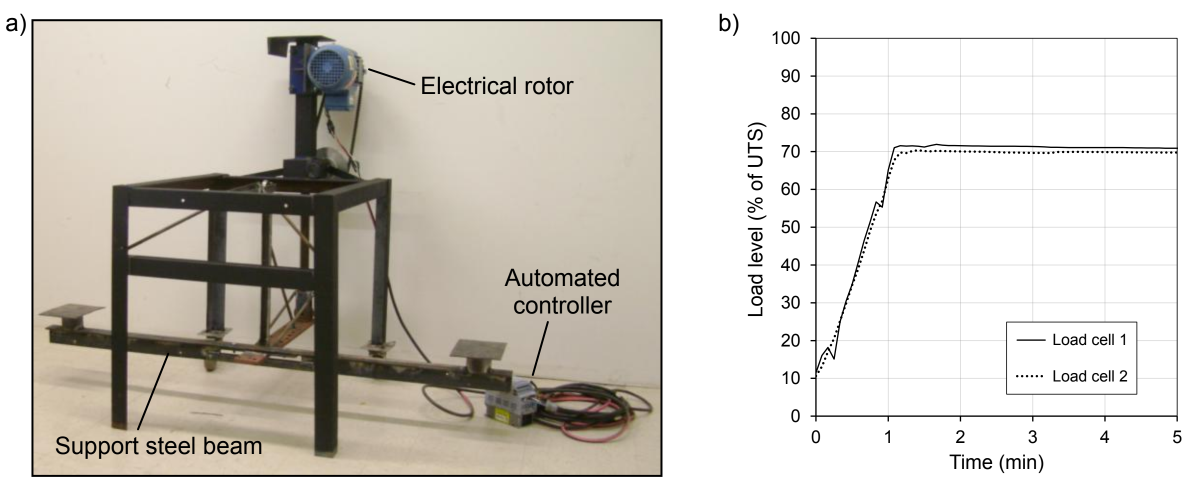


Figure 2 – New apparatus implemented to the loading system of the new creep testing equipment: a) General view; b) Load level during the first five minutes of a confined-accelerated creep test performed with a nonwoven geotextile.

The new equipment requires 1,100 mm long geosynthetic specimens. However, the specimen preparation procedure consists of reinforcing the outermost portions with a two-component adhesive in order to result in two rigid, smooth surface regions. Consequently, only the central segment (100 mm long and 200 mm wide) is subjected to creep deformations during the tests. This segment is reported as "length of interest" in this paper. At the end of the specimen preparation procedure, two pieces of stainless steel wires are attached and glued in the length of interest of the specimens. They are connected to displacement transducers in order to measure the displacement of each of these two points. Then, specimen elongation is computed by the sum of both values divided by the initial distance between them.

The new creep testing equipment is also provided with an automated data acquisition system. It is responsible for registering reading from thermocouples, load cell and displacement transducers.

3. CREEP TESTS

The new creep testing equipment was used in three different types of tests: confined, accelerated and confined-accelerated. Tests with in-soil specimens conducted at room temperature are referred as confined creep tests. On the contrary, tests conducted with in-isolation specimens and under elevated temperature are named accelerated creep tests. Finally, tests in which both measures were used simultaneously are entitled confined-accelerated creep tests in this paper. Besides, creep tests conducted under the regulations presented by ASTM D 5262 are referred as conventional creep tests and were performed in order to characterize geosynthetics creep behavior regarding the current practice. The following sections describe the materials used and the tests performed during this study. Moreover, the results from such tests are presented and discussed.

3.1 Geosynthetic Materials and Chamber Fill

Two different geosynthetic materials were used in the creep tests presented in this paper: a nonwoven geotextile and a biaxial geogrid. Both geosynthetic materials were manufactured with polyester fiber. Table 1 summarizes the main characteristics of each geosynthetic material.

Table 1. Characteristics of tested geosynthetic materials.

Characteristics	Nonwoven geotextile	Biaxial woven geogrid
Manufacturing process	Needle punched	Woven
Predominant polymer	Polyester	Polypropylene
Mass per unit area (g/m²)	263 (6.1%)[1]	N/A[2]
Aperture size (mm)	N/A[2]	35.0
Nominal thickness (mm)	2.8 (5.6%)[1]	N/A[2]
Tested direction	Cross-machine direction	Machine direction
Short-term tensile strength (kN/m)	14.11 (12.4%)[1]	19.72 (1.9%)[1]
Elongation at rupture (%)	68.12 (9.34%)[1]	9.6 (4.4%)[1]

[1]the numbers in parentheses correspond to the coefficient of variation computed in each parameter.
[2]non-applicable.

Confined and confined-accelerated creep tests were performed with testing chamber filled with a dry poorly graded sand sample, classified as SP according to USCS system. Its coefficient of uniformity and coefficient of curvature were equal to 1.01 and 0.72, respectively. Maximum dry density of 16.7 kN/m³ and minimum dry density of 15.0 kN/m³ were found for the sand sample used as confining medium. The sand was used with density equal to 45% of its maximum dry density. Direct shear tests at this condition resulted in peak friction angle equal to 34.4° and residual friction angle equal to 27.5°.

3.2 Tests Performed

Firstly, the creep behavior of both geosynthetic materials were determined by means of conventional creep tests (ASTM D 5262). In fact, the geogrid was not subjected to other types of creep tests so far in this research. The nonwoven geotextile was also used in accelerated, confined and confined-accelerated creep tests. Tests with in-soil specimens were performed under normal stress of 50 kPa. Accelerated and confined-accelerated creep tests were conducted under different test temperatures. Note that some tests were performed until specimens rupture (creep rupture tests). Table 2 summarizes the characteristics of the creep tests presented in this paper.

Table 2. Characteristics of creep tests.

Type of creep test	Nonwoven geotextile				Biaxial woven geogrid
Conventional	20 to 60% of UTS[1] 1000 h; Room temperature				20 to 50% of UTS[1] 80 to 95% of UTS[1] 100 h; Room temperature
Accelerated	50% of UTS[1] 112 h; 35.1°C	---	---	---	---
Confined (50 kPa)[2]	50% of UTS[1] 160 h; 26.0°C	70% of UTS[1] 131 h; 24.1°C	80% of UTS[1] 160 h; 24.4°C	90% of UTS[1,3] 0.78 h; 24.5°C	---
Confined-accelerated (50 kPa)[2]	50% of UTS[1] 131 h; 36.9°C	70% of UTS[1] 191 h; 36.9°C 265 h; 47.7°C 464 h; 59.1°C[3]	80% of UTS[1,3] 17.5 h; 36.5°C	---	---

[1]Ultimate tensile strength from short-term tensile test.
[2]Confining pressure applied during the test.
[3]Creep rupture test.

3.3 Creep test results and analysis

Nineteen creep tests are presented in this paper. Among them, ten tests were conducted with the new creep testing machine developed by França (2012). Despite geosynthetics creep curves are commonly plotted as specimen elongation versus time in logarithmic scale, the effects of temperature and soil-geosynthetic interaction in creep strains are not clearly identified since this representation reflects both initial and creep strains. On the contrary, Zornberg et al. (2004) proposed a creep curves representation in which only the creep strain of the specimens are used. In this plot, the creep strains are plotted versus the logarithm of the ratio between the current time and the time at the end of load application. Moreover, the slope of the resulting line indicates the rate of creep strain occurrence during the tests, which is designated as creep index (T_α). Hence, creep index values can be used to indicate the effect of any parameter in creep strains of any geosynthetic material. Due to this aspect, the representation suggested by Zornberg et al. (2004) was used in the analysis of the creep tests presented in this paper.

3.3.1 Nonwoven Geotextile

Different creep test types were performed with the nonwoven geotextile. Initially, tests conducted at conventional conditions and at 50% of the ultimate tensile strength (UTS) in non-conventional conditions were used to quantify the geotextile creep behavior regarding creep deformations. Figures 3a and 3b present the results obtained in conventional creep tests with specimens subjected to 20 to 60% of UTS and in creep tests under both conventional and non-conventional conditions with specimens loaded to 50% of UTS, respectively. Note that a few points are represented in this plot in order to make it clearly. However, data acquisition was performed with one minute intervals. This measure was used in every plot presented in this paper.

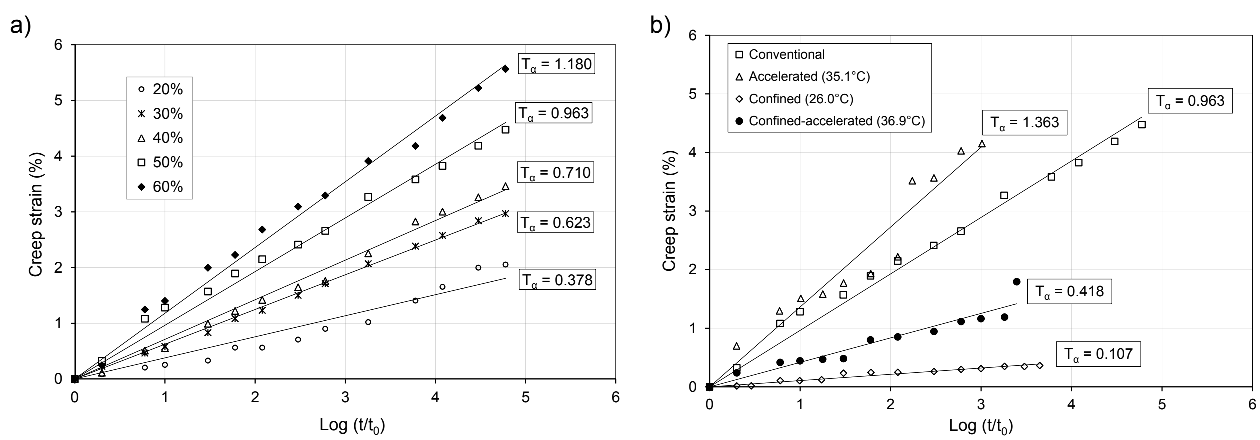


Figure 3 – Results from creep tests conducted with the nonwoven geotextile: a) Conventional creep tests with specimens subjected to load levels from 20 to 60% of UTS; b) Creep tests under both conventional and non-conventional conditions with specimens subjected to 50% of UTS.

Unsurprisingly, nonwoven geotextile creep index values are proportional to the load applied to the specimen during the test. The relationship between load levels and creep index values is approximately linear, with slope equal to 0.019 (coefficient of determination of 0.98). Regarding the specimens subjected to 50% of UTS, the nonwoven geotextile creep behavior was found to be highly affected by soil confinement in the tested conditions. A normal stress of 50 kPa was able to reduce the creep index to approximately 11% of the value obtained in the conventional condition. Note that both tests were performed at room temperature. A similar trend was found at elevated temperatures; however, the creep index change was slightly less significant. Creep index value in confined-accelerated creep test (36.9°C) was approximately equal to 30% of the one obtained in accelerated creep test (35.1°C).

Creep strain reduction due to creep reached significant levels at room temperature. Note that the creep index obtained in the confined test with the specimen loaded to 50% of UTS is smaller than the one found at conventional conditions with the specimen subjected to 20% of UTS. It indicates the high influence of soil confinement in this geotextile creep behavior. However, it is important to mention that this condition cannot be extrapolated for every nonwoven geotextile in every condition. At elevated temperature, creep index reduction was not as substantial as found at room temperature. Besides, different loading systems may induce unlike behavior, as reported by Elias, et al. (1998) and Costa (2004).

In addition to the tests described so far in this paper, a new set of tests was performed at 70, 80 and 90% of UTS with geotextile in-soil specimens. It was used to characterize the geosynthetic creep rupture behavior in confined condition. Firstly, a creep rupture confined test at 90% of UTS was performed, which caused specimen rupture approximately after 47 minutes (0.78 h). It was followed by two confined creep tests with specimens loaded to 80% of UTS, at room temperature and with temperature equal to 36.5°C. The specimens rupture did not occur in the test conducted at room temperature (until 160 h) and took place after 17.5 h at elevated temperature. Finally, four creep tests were performed with in-soil specimens loaded to 70%of UTS (at room temperature and at temperature values equals to 36.9, 47.7 and 59.1°C). The rupture only occurred at the highest temperature after 464 h.

The set of creep tests conducted with in-soil specimens loaded to 70 and 80% of UTS at elevated temperature (confined-accelerated creep tests) was interpreted in order to establish the creep master curves for each load level. Additionally, the confined creep test at 90% of UTS was used to determine the time to rupture at this load level. Figure 4a presents the creep master curves for specimens loaded to 70 and 80% of UTS. Moreover, Figure 4b presents the creep rupture curve found with this set of tests.

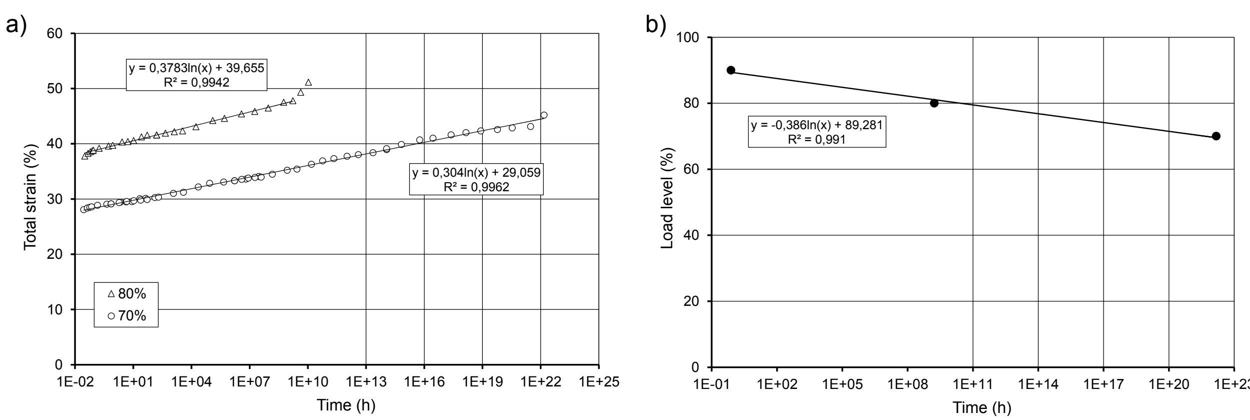


Figure 4 – Results from confined creep tests conducted with the nonwoven geotextile: a) Creep master curves for specimens loaded to 70 and 80% of UTS; b) Creep rupture curve obtained with in-soil specimens.

Creep rupture curves are used to determine the reduction factor due to creep behavior. This parameter is considered in the computation of the geosynthetics tensile design strength. Note that the reduction factor due to creep obtained with the tests performed so far would reach lower values than those suggested in the technical literature (1.5 to 3.0). For instance, the reduction factor obtained from the data presented in Figure 4b is equal to 1.20 for a service life of 50 years. However, it is important to mention that this computation is based on one single set of tests and comprises preliminary results with this geosynthetic material. Further tests are predicted to be conducted with the nonwoven geotextile using in-isolation specimen. As a result, the creep behavior at higher load levels (70 to 90% of UTS) with in-isolation specimens will be compared with that found with in-soil ones.

3.3.2 Biaxial Woven Geogrid

The biaxial woven geogrid was subjected to fewer creep tests in this research. In fact, only conventional creep tests have been performed so far. These tests were used to evaluate both creep deformations, with specimens loaded from 20 to

50% of UTS, and to determine the creep rupture curve, with specimens subjected to loads from 80 to 95% of UTS. Figures 5a and 5b presents the plots from each set of tests.

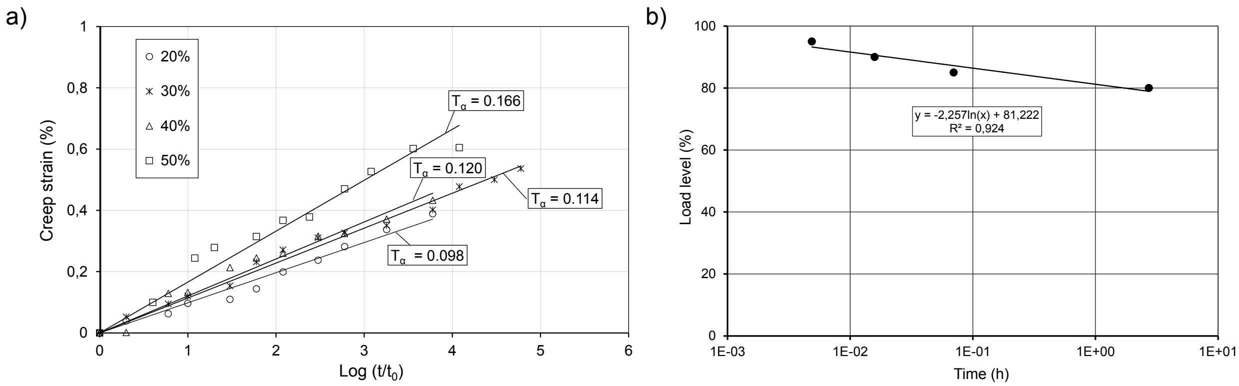


Figure 5 – Results from creep tests conducted with the biaxial woven geogrid: a) Conventional creep tests with specimens subjected to load levels from 20 to 50% of UTS; b) Conventional creep rupture curve obtained with specimens subjected to loads from 80 to 95% of UTS.

The creep index was found to be proportional to the load level, as expected for any geosynthetic material. According to the creep rupture curve, the reduction factor due to creep would be approximately 1.9 for a service life of 50 years. However, it is important to notice that this value refers to an approximate prediction since it is based on very few tests and the extrapolation process exceeded the recommended standard of one order of magnitude (ASTM D 5262).

Further tests are predicted to be conducted with the geogrid. Firstly, these tests will comprise complimentary creep rupture tests with in-isolation specimens and confined creep rupture tests using in-soil specimens. Tests with specimens loaded to lower load levels will be accelerated by elevating the test temperature. Thus, creep master curves will be established and time to rupture will be determined at these load levels. Creep rupture tests will be followed by confined creep tests at lower load levels in order to determine the effect of soil-geogrid interaction on the geosynthetic creep behavior.

4. CONCLUSIONS

This paper presented a brief description of the creep testing equipment developed by França (2012) to conduct simultaneously confined and accelerated creep tests on geosynthetics. It was also presented an additional improvement, which was implemented to its loading system. A nonwoven polyester geotextile and a biaxial woven geogrid were subjected to different creep test series. The following conclusions are drawn from the present study:

- The influence of soil-geosynthetic interaction in creep strains of the nonwoven geotextile was found to be very significant at both room and elevated temperature. Creep index values were reduced to 11 and 30% of those found with in-isolation specimens at room temperature and at 35.1°C, respectively.
- Creep rupture tests conducted using nonwoven geotextile specimens under confined condition led to reduction factors due to creep considerably lower than those usually applied in geotechnical structures design. However, this aspects still requires further investigation.
- Preliminary creep tests using biaxial woven geogrid indicated an expected creep behavior for this geosynthetic material (creep index was proportional to load level).
- A conventional creep rupture curve was suggested for the biaxial woven geogrid. Despite it was based only on four load levels, extrapolation of this curve led to recommended values.
- The new creep testing equipment performance was improved by adding the new loading system. It was able to apply the creep load at a constant rate on both sides of the specimen simultaneously;
- Further tests are predicted with both the nonwoven geotextile and the biaxial woven geogrid. Additional creep tests with other geosynthetic materials are also predicted in order to develop a larger data base regarding in-soil creep behavior of different types of geosynthetics.

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