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Chemical ageing and creep analyses - influence of synergy and test specimen preparation

Trentini, R.S., Vidal, D. & Martins, P.M.
Instituto Tecnológico de Aeronáutica – ITA – Brazil

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ABSTRACT: Reduction factors are currently considered in geosynthetic reinforcement systems design and this concept is largely accepted by designers and manufacturers. However, the synergy between the degradations processes and the actual approach to determine total reduction factor (RF_T) from partial factors considering effects as creep (RF_{CR}), mechanical damage (RF_{ID}) and chemical ageing (RF_{CA}) are questioned and need more research. This work discusses synergy effects between creep and chemical ageing from analyses conducted on polyester yarns tensioned in alkaline solution ($Ca(OH)_2$ at pH 12). The tests carried out show an important synergy between these factors. The influence of the previous specimen preparation, considering scouring and wetting is also discussed.

1 INTRODUCTION

The reduction factor concept was largely accepted by designers and manufacturers to estimate geosynthetics functional properties from characteristic or index properties (Koerner 1998). The conventional approach determines the total reduction factor (RF_T) by the product of partial factors considering, for instance, creep (RF_{CR}), mechanical damage (RF_{ID}) and chemical ageing (RF_{CA}), multiplied by a safety factor which allows considering fabric variability and synergy effects, among others.

Several researches have been conducted considering the effects of installation damage on the long term behaviour of geosynthetics acting as reinforcement. A number of these studies comments that the current approach is conservative and to consider a combined factor, as $RF_{ID \times CR}$, is essentially different than considering $RF_{DI} \times RF_{CR}$ (Allen & Bathurst 1996, Pinho Lopes et al. 2002, Greenwood 2002).

Viezee et al. (1990) complement these analyses considering chemical ageing effects on creep performance. Their creep tests had been conducted on polyester yarns specimen previously stored unloaded in alkaline solutions. The authors comment that chemical ageing effects couldn't be detected after 3 months. However, other studies observed ageing effects on polyester nonwoven geotextiles stored in the same alkaline solution, but in scoured specimen conditioned in a wetting agent before storing.

Recently, researches evaluating tensile influence on polyester yarns hydrolyses in alkaline media have observed that the chemical ageing increases when the yarn tensile stress increases (East & Rahman 1999 Rahman & Alfaro 2004).

The aim of this paper is to discuss the synergy between creep and chemical ageing reduction factors, and the influence of the previous specimen preparation, considering scouring and wetting, in the performance of polyester geosynthetic long time analysis. Some results of tests carried out on polyester yarns to evaluate synergy effects between creep and chemical ageing reduction factors at rupture condition are presented.

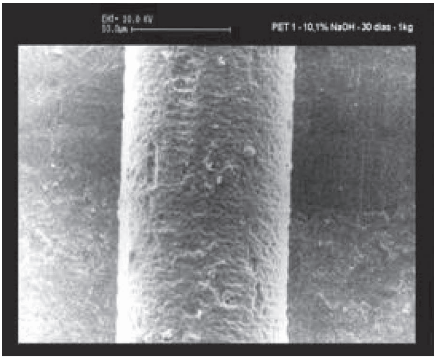
2 PREVIOUS YARN RESEARCHES

Tests considering yarn specimen are easier to be developed and are often chosen to perform analysis to study chemical ageing effects. Small loads and reservoirs reduce costs but need careful and accurate procedure.

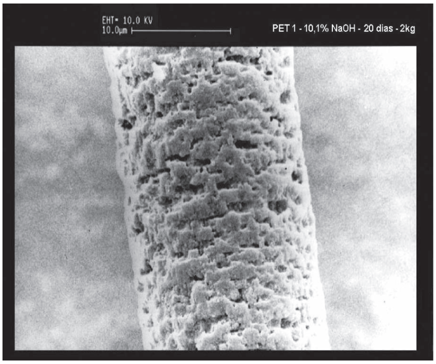
A large number of works discussing yarns behaviour have been published. Among these works, the papers of East & Rahman (1999) and Rahman & Alfaro (2004) present test results directly concerning the subject of this paper.

The authors tested pre-tensioned polyester yarns scoured in an alkaline solution (NaOH) and alert to two main questions: tensile loads act as a catalyze factor in chemical ageing and the influence of the specimen preparation procedures in this kind of analyses.

An increase in the lost mass and a tensile strength decrease were observed when pre-tension increased. Figure 1 shows the relevance of pre-tension in chemical ageing effects. Rahman & Alfaro (2004) repeat East & Rahman (1999) tests scouring yarns before pre-tension application. They observe, under the same test condition, an increase in lost mass of up to 70%.



(a) after 30 days immersing in NaOH solution – yarn pre-tensioned at 1000 g



(b) after 20 days immersing in NaOH solution – yarn pre-tensioned at 2000 g

Figure 1. Polyester yarns tested by East & Rahman (1999).

3 CONVENTIONAL REDUCTION FACTOR ANALYSIS

3.1 *Tests conditions*

All tests are conducted in a special room at (32 ± 2)°C. The yarn specimens were scouring at distilled water with a wetting agent for 25 min washed and placed to rest for 24 h before tests.

For chemical ageing a $Ca(OH)_2$ solution at pH12 was prepared from CaO at 5 g/L in distilled water. Trentini (2005) presents details of the procedures adopted for all tests.

3.2 *Creep rupture behaviour*

The first step to evaluate creep rupture behaviour is a conventional tensile strength test on virgin specimen. Table 1 presents some results of the tests conducted on nine specimen of the polyester yarn chosen for this research, according ASTM D 3822, under a speed of 25 mm/min.

Table 1. Virgin yarn tensile strength (tests at 25 mm/min).

	minimum	maximum	average	CV (%)
α_{max} (N)[1]	6.4	6.9	6.7	2.1
ε_{rupt} (%)[2]	26	31	29	6.1
$J_{sec50\%}$ (N/mm)[3]	0.12	0.21	0.19	14.4

[1] maximum load
[2] strain at maximum load
[3] secant stiffness at 50% of strain

Creep rupture tests are conducted according to ISO/ENV13431 (1999) considering 74%, 78%, 83% and 88% of the average maximum load value given at Table 1 (6.7 N). At least six specimen were tested for each load level.

The procedure established for geotextiles and related products can be applied to yarns but special care needs to be taken for load application. Best results were obtained applying loads slowly, moving down the load system fixed to the yarn at 10mm/min, stopping one minute each 10mm until complete yarn loading (Trentini 2005).

3.3 *Tensile behaviour under chemical ageing*

To obtain the chemical ageing reduction factor yarns were stored at different times in alkaline solution ($Ca(OH)_2$ – pH12) and submitted to tensile strength tests at 25 mm/min. The recipients with yarn specimen immersed in alkaline solution had been shook and the pH verified each 24 h. The specimen to be submitted to tensile strength tests (according to ASTM D 3822 at 25 mm/min) were washed in distilled water after chemical ageing time and rest for 24 hours before testing.

Tensile tests were conducted on specimens immerged for 0.6, 1, 3, 125, 168, 213, 200 and 321h. At each time at least seven specimen were tested and the average tensile strength was considered to determine the related reduction factor by comparison with the maximal load obtained for virgin yarns.

4 CREEP UNDER CHEMICAL AGEING TESTS

Special equipment, illustrated in Figure 2, was developed to apply a constant load to yarn immersed in alkaline solution. A calibration analysis needs to be done to determine the real load applied to the yarn

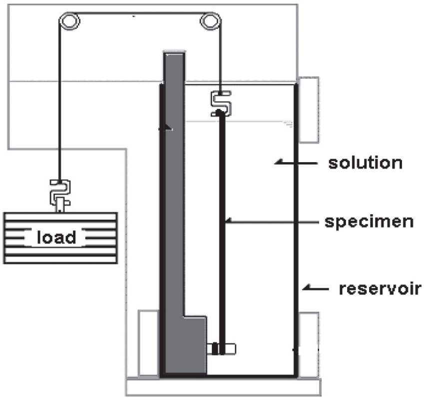


Figure 2. Test equipment to creep under chemical ageing tests.

specimen, even when a special system to reduce friction is employed.

Loads must be applied carefully, as described at item 3.2 for creep tests, and the alkaline solution need to be shaken and the pH verified each 24 h (Trentini 2005).

Creep rupture tests under chemical ageing are conducted considering 60%, 65%, 71%, 76% and 85% of the maximum load value (Table 1). For each load level 05 specimens were tested.

Figure 3 presents some of the obtained results and illustrates a comparison between the three test results, evidencing the synergy effects.

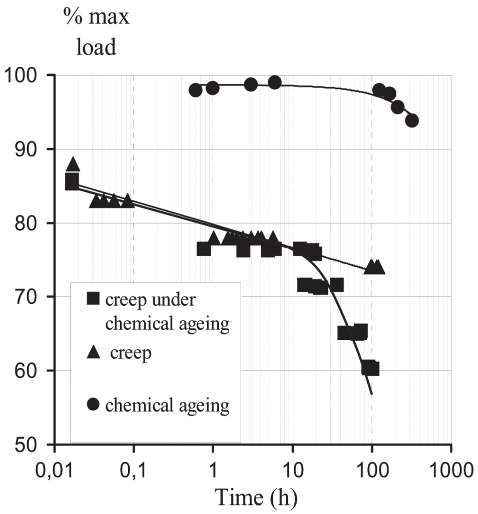


Figure 3. Time effects on tensile strength for the ensemble of tests.

5 REDUCTION FACTORS

Partial Reduction Factors represent the relationship between index properties and functional properties observed on tests. Total Reduction Factor (RF_T) considering only partial reduction factors due to creep (RF_{CR}) and chemical ageing (RF_{CA}) can be obtained by (Koerner 1998):

$$RF_T = RF_{CR} \times RF_{CA} \quad (1)$$

Table 2 resumes the reduction factors obtained by conventional procedure and Table 3 compares these values with the reduction factor obtained from creep tests under chemical ageing and presents the necessary reduction factor (or security factor), RF_{SE}, to be applied on conventional analysis to get the same results that creep under chemical ageing results.

Table 2. Conventional reduction factor time variation.

Time (h)	Chemical ageing %max load	Chemical ageing RF	Creep %max load	Creep RF	RF $RF_{CR} \times RF_{CA}$
1	99	1.01	80	1.25	1.26
5	99	1.01	78	1.29	1.29
10	99	1.01	77	1.30	1.31
20	98	1.02	76	1.32	1.34
50	98	1.02	74	1.34	1.37
100	97	1.03	73	1.36	1.40

Table 3. Comparison between conventional RF and obtained values considering creep under chemical ageing.

Time (h)	Conventional RF $RF_{CR} \times RF_{CA}$	Creep under chemical ageing %max load	Creep under chemical ageing RF_{CR+CA}	synergy effects[1] RF_{SE}
1	1.26	78	1.28	1.02
5	1.29	76	1.32	1.02
10	1.31	75	1.33	1.02
20	1.34	73	1.37	1.02
50	1.37	68	1.47	1.07
100	1.40	59	1.69	1.21

[1] $RF_{SE} = RF_{CR+CA}/(RF_{CR} \times RF_{CA})$

Figure 4 allows evaluating time effect increasing the difference between both procedures and the importance of performing special tests when tensile solicitations and chemical ageing could be present.

6 FINAL COMMENTS

The main proposal of this paper is to discuss the conventional concept of the reduction factors obtained by the product of partial factors when chemical ageing could be associated to mechanical solicitations. Synergy effects in this case are time function and it is very difficult to estimate the corresponding factor to be considered. To simplify these preliminary analyses, tests with polyester yarns and a very high alkaline solution were conducted.

To analyse synergy effects between creep and chemical ageing, tensile failure loads of unloaded

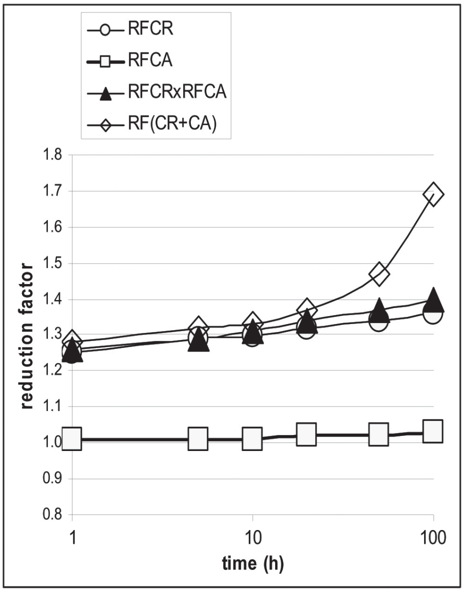


Figure 4. Time increasing of the reduction factor.

yarns stored on $Ca(OH)_2$ solution at pH 12 had been compared with virgin yarns test results to obtain RF_{CA}. Furthermore, conventional creep tests and specially developed long term tests associating creep and chemical ageing had been conducted to obtain the RF_{CR} and RF_{CR+CA}, respectively.

Test results evidence an important synergy effect between creep and chemical ageing for polyester yarn tensile in an alkaline solution at pH12. The reduction factor considering creep under chemical ageing after 100h is 20,7% bigger than the product of the creep and chemical ageing reduction factors at the same time and the results indicate a tendency to increase this difference.

These results, even considering that pH12 is a very high alkaline environment, indicate that special attention needs to be given to chemical ageing under tensile conditions and the reduction factor estimation in this case.

Another important point to be considered is that, to get the critical conditions that could be present in field, geosynthetic specimen must be prepared with special care, scoured and wetted before being submitted to chemical ageing.

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