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Testing durability of polyester to be used in earth-reinforced structures

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ABSTRACT: The durability of polyester yarn used in geotextiles is governed by its resistance to hydrolysis which is the main degradation reaction for this type of polymer. After recalling the different parameters that influence hydrolysis and the results obtained by Terre Armée Internationale in testing PETP at 95 °C in 27 media, the paper presents the first results related to the second phase of this research program. Five different polyester yarns have been exposed at 80 °C in three media. The results show that low tenacity fibers are more affected by alkaline media than high tenacity yarns. A third phase of the research program will complete the data at lower temperatures in order to assess performance in soil and to define appropriate durability safety factors.

1 INTRODUCTION

Since research on the long term performance of polymers in soil has been recognized as a major issue for the development of geosynthetics, producers as well as users have initiated significant laboratory research programs.

Terre Armée Internationale took part in the research effort by setting up in 1990 an original research program devoted to the long term performance of Polyethylene Terephthalate fibers and yarns used in geotextiles with reference to their hydrolytic degradation.

Results of the first phase are already published. They concerned hydrolysis of PETP at 95 °C in 27 media. For the first time, the relationship between the rate of hydrolysis and pH (values between 1 and 13) was established.

This paper presents the preliminary results of the second phase of this research program in which five different polyester yarns have been exposed at 80 °C in 3 media.

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2 HYDROLYSIS OF PETP

From previous work it is clear that hydrolysis is the principal degradation phenomena for polyester. The rate of degradation due to hydrolysis is slow in normal conditions of use.

Hydrolysis is the inverse reaction of esterification. Ester is created by the reaction between an organic acid and an organic alcohol. The by-product is a water molecule.

acid + alcohol —> ester + water

To generate polyester, a di-acid (terephthalic acid) and a di-alcohol (ethylene glycol) are used in order to create a chain of ester groups. The number of repeating groups may vary , thus producing different chain lengths. Long chains correspond to high molecular weight and high mechanical strength.

This mechanical strength is improved by drawing the filaments during the manufacturing process. The result is an orientation of molecules that become parallel to the direction of drawing and increase the tensile strength in that direction. The material is susceptible to partial crystallization, leaving amorphous matter between the crystals linking them together. This amorphous phase is more vulnerable to hydrolysis than the well organized and compact crystals. The amorphous phase is glassy (high tensile modulus) at ambient temperatures and is responsible for good resistance to creep phenomena. It becomes rubbery (lower modulus) at temperatures above the "glass transition temperature" (T_g) which is approximately 65 °C. Very little is known about the possible change in the hydrolytic degradation kinetics at the transition temperature.

The hydrolysis kinetics depends on :

• the matter itself
 - molecular mass by number (related to number of carboxyl end-groups) or by weight (assessed by viscosimetry),
 - orientation
 - also to a lesser extent . crystallinity
 . polydispersity and
 . surface treatment

• the environment
 - temperature
 - relative humidity
 - pH in general and mainly the nature of alkaline chemical products
 - also to a lesser extent . UV exposure and
 . mechanical stress

The effect of these parameters on hydrolysis rate is summarized below :

Increase in :	Hydrolysis rate :
(1) Molecular weight	decreases
(2) Degree of orientation	decreases
(3) Crystallinity	decreases
(4) Polydispersity	increases
(5) Temperature	increases
(6) Relative Humidity	increases
(7) pH > 10	increases
(8) UV exposure	increases
(9) Mechanical stress (not proven)	may decrease

As hydrolysis progresses, the polymer chains break and become shorter and shorter thus reducing the internal cohesion in the matter. The tensile strength decay is one of the consequences and can be easily measured.

The first four parameters summarized above depend on the source of the yarns. In the second phase, five different yarns or filaments were tested, four being high tenacity polyester, one being a low tenacity filament used to produce non-woven geotextiles.

Temperature is used as the accelerating factor in the testing. Only high temperature testing gives significant results in a reasonably short time. The rate of hydrolysis depends on temperature according to Arrhénius' law with an activation energy of 25000 cal/mole. This value is calculated from test results obtained at temperatures above T_g. Sound and precise long term data is not available to confirm that this value of activation energy is still valid for lower temperatures.

The influence of humidity has been established by McMahon *et al.* (1959). The hydrolysis rate is directly proportional to the relative humidity of air. A saturated condition (of air in pore space) prevails in soils where water is always present. This parameter is thus fixed to 100 %. In our research program the material was fully immersed in liquid media and therefore represents a fully saturated condition.

The influence of pH was extensively studied in phase one. The results are presented in figure 1.

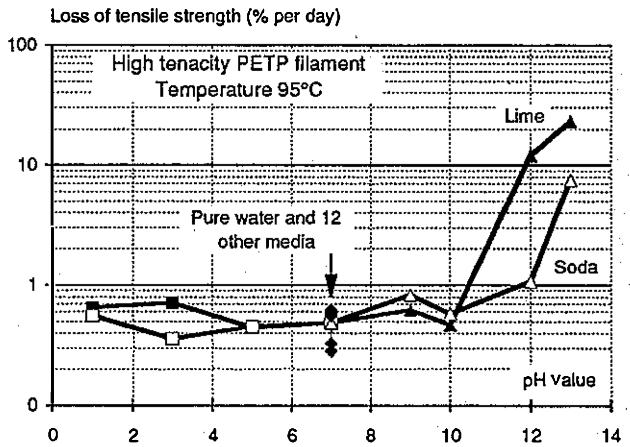

Fig.1 Hydrolysis rate versus pH, at 95 °C

Table 1 Summary of phase 1 investigations on PETP high tenacity filament degraded at 95°C

Media:	Refer.	Lime pH 12	Soda pH 12	Pure water	HCl pH 1
Time (days)	0	2.5	28	70	56
Strength retained	100 %	70	70	70	70
Relative Mw (1)	100	93.5	78.4	45.5	27.3
Erosion	-	strong	light	none	none

(1): "Relative Mw" values represent molecular weight measured by viscosimetry.

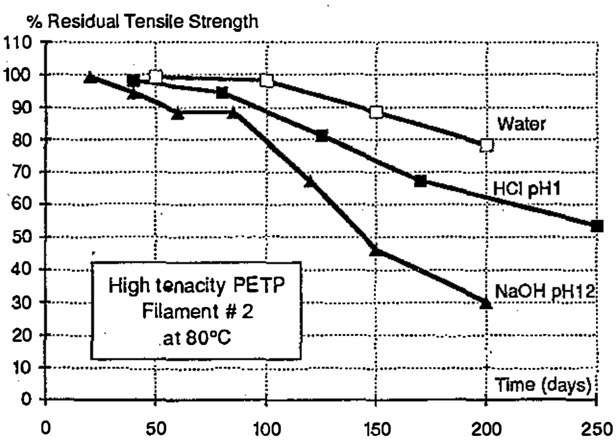

Fig. 2 Behavior of one high tenacity PETP yarn in the three selected media at 80 °C

We confirmed that lime is more aggressive than caustic soda at pH values greater than 10. In real structures there is evidence of the aggressivity of lime (or concrete) on high tenacity polyester, even at ambient temperature. In our opinion it is not advisable to use polyester in applications where the environment has a pH greater than 10, be it only locally. This condition should be included in general specifications on the use of polyester based geotextiles.

At neutral pH values we have tested the performance of high tenacity polyester filaments exposed to 12 different salty solutions at 95 °C for 70 days, including :

- 500 and 5000 ppm $CaCl_2$ (de-icing salt)
- 500 and 5000 ppm $CaSO_4$ (gypsum) and
- sea water

The degradation of tensile strength was identical to the degradation observed in pure water. Thus the presence of calcium has no influence at neutral pH values, within the conditions of testing.

Further investigations were performed on filaments that have lost 30 % of their original tensile strength in four very different media as shown in Table 1.They confirmed that high pH values give rise to a quick erosion of the fiber ("outer" hydrolysis). In less aggressive conditions, the degradation affects the entire core of the fiber ("inner" hydrolysis) but at a much lower rate. The "outer" hydrolysis observed at high pH values develops at a very high rate compared to the "inner" hydrolysis. Therefore, almost no change is observed in the core of the filament (molecular weight for example). Both phenomenas are although present.

3 TESTING PROCEDURE AND RESULTS

For the second phase of our research program, the four high tenacity yarns came from three different producers. They all fall in the same range of mechanical characteristics and are actually used in geotextiles and related products used for reinforcement. The fifth is a low tenacity fiber used to produce non woven geotextiles. A similar grade is used in some applications where yarn and sand are directly mixed during construction to form a cohesive mass that act as a retaining structure.

These materials were immersed in three different media selected from the first phase of the program : pure water, hydrochloric acid (pH 1), and caustic soda (pH 12).

Samples were retrieved according to a predefined schedule and tested for their mechanical characteristics (rupture strength and elongation at rupture).

Figure 2 shows the typical performance of a high tenacity polyester yarn in these media. We observed the same pattern in the hydrolysis rate in the results from phase one. Since strength decay varies with time, it is interesting to note the slope of the curve between 85 % and 70 % strength loss. We note that the degradation rate observed in water is multiplied by about 2 to obtain the rate in the acid media, and 4 to obtain the rate in soda.

The beginning of the curves is affected more or less by the shrinkage due to exposure to high

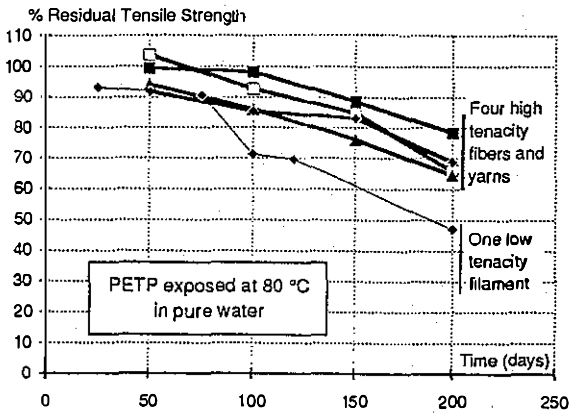

Fig. 3 Comparison of strength decay for five PETP materials exposed at 80°C in water

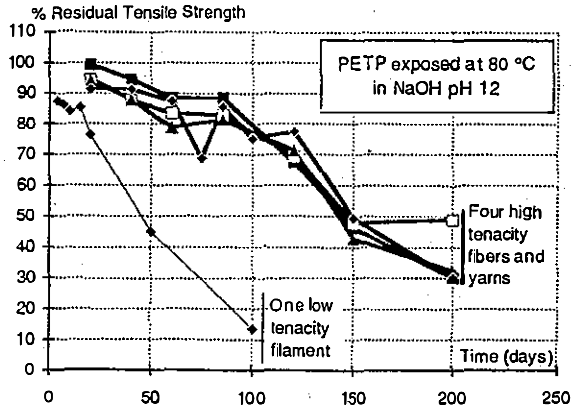

Fig. 4 Comparison of strength decay for five PETP materials exposed at 80°C in soda

temperature (fibers are left loose in the media) and also by the nature of the media.

Figure3 presents a comparison between the performance of the different fibers and yams. One can observe that a general trend is followed by all matcrials: the slopes of the five curves are similar. However the low tenacity yarn exhibits a significantly greater strength loss.

A similar comparison is reported in figure 4 in alkaline media. For this media the curves corresponding to the four high tenacity materials are well grouped. The low tenacity fiber supports a strength decay due to hydrolysis that is about five times greater than the rate observed for high tenacity yarns. It is therefore advisable to exercise caution when such material is used for long term applications.

4 FUTURE DEVELOPMENT

Data at low temperatures is still needed. The third phase of the research program (currently underway) includes 50 °C and 25 °C temperature conditions. The same media, pure water, HCl pH1 and NaOH pH 12 is used. Saturated lime is also included with a shorter retrieving schedule at 50 °C.
The retrieving schedule is as follows :
For water, HCl pH1, NaOH pH12 at 25 °C and 50 °C, and saturated lime at 25 °C:
6 months, 1 year, 2 years, 5 years, 10 years, and 15 years,
for saturated lime at 50 °C :
1 month, 3 months, 6 months, 1 year, 1.5 years, and 2 years.

5 CONCLUSIONS

The first two phases of this research program have already produced data which will help to better understand the mechanism of degradation and to quantify the effects of hydrolysis on polyester products. The initial results of the second phase confirmed the influence of the polyester tenacity on the resistance to hydrolytic degradation.

We believe that the knowledge resulting from this research program, when it is completed, will help engineers to design long term structures with appropriate factors of safety. We hope that other organizations interested in this field will join us to continue this research effort.

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