LONG TERM PERFORMANCE OF GEOTEXTILES

Andre L. Rollin, ing., F_{eic}, F_{csme}, Montreal, Canada

ABSTRACT
Geotextiles installed in many geotechnical and environmental works must have a short term performance in retaining sol particles, filtering liquids, be a separator between sols, protect geomembrane against puncture and to accomplish many other functions. Their short term performance, survivability, is related to the engineering design of the work, to the CQA manufacture, to their installation. and the chemical nature of the products in contact. How long is the expected service life of a geotextile when installed in a earth structure and in contact with atmospheric conditions and chemical products ?

RÉSUMÉ
Les géotextiles installés dans un ouvrage de géotechnique ou de protection de l'environnement doivent être performants à court terme pour retenir les sols en place, pour filtrer et évacuer des liquides, pour séparer des couches de sols, pour protéger des géomembranes contre le poinçonnement et pour accomplir plusieurs autres fonctions. Cependant ces matériaux doivent être performants durant une longue période de temps. Quelle est la durée de vie fonctionnelle des géotextiles que l'on peut espérer en fonction des conceptions utilisées, des programmes de contrôle de la qualité durant la construction et la mise en oeuvre, de la nature des sols et des produits en contact?

1. INTRODUCTION

When a geotextile is used in a civil engineering structure, it is intended to perform a particular function for a minimum expected time, called the design life. A geotextile is a planar, permeable, polymeric (synthetic or natural) textile material, which may be woven, knitted or non-woven, used in contact with soil and/or other materials in geotechnical and civil engineering applications. Any application may require one or more functions from the geotextile such as filtration, protection, reinforcement, separation and surface erosion control. Each function uses one or more functional properties of the geotextile, such as tensile strength or water permeability.

Assessment of the durability of an application using geotextiles requires a study of the effects of time on the functional properties. The textile and polymer structures, the manufacturing process, the physical and chemical environment, the conditions of storage and installation, and the different solicitations supported by the textile are all parameters which govern its durability. The main task is to assess the evolution of the functional properties for the entire design life of the application.

The durability is related to the change of a property of an installed geotextile with time. Figure-2 is a schematic representation of the evolution of the available property of a material as a function of time, as represented by the curves on the graph. Along the time axis is indicated the events that happen between manufacture of the product and the end of product life. Each curve represents the changes in the required property during these different and successive events. One can see that after the loading phase, the property required is considered to be constant and equal to the level defined by the design.
The design life is specified on the time axis. It is set by the designer and one of several fixed durations must be set according to whether the structure is meant for short-term use (typically a few years and not exceeding 5 years), temporary use (around 25 years) or permanent use (50 to >100 years). The nature of the structure, the environmental risk involved and the consequences of failure may influence this duration: 70 years for a wall, 100 years for an abutment and beyond 100 years for landfills.

Many geotextiles have a temporary function although the system is permanent, for example an embankment over a weak soil may require a geotextile reinforcement until the embankment has settled.

At the end of the anticipated design life, the designer has to ensure a certain safety level, such that failure is predicted to be well beyond the design life. As shown in Figure-1, the variation of a property with time under condition I is significant but the degradation is not great enough to affect the performance of the application since the long term value is greater than the acceptable limit. On the other hand, the same property did degraded faster under condition II to a value lower than the acceptable limit putting in peril the application: the geotextile cannot perform its function.

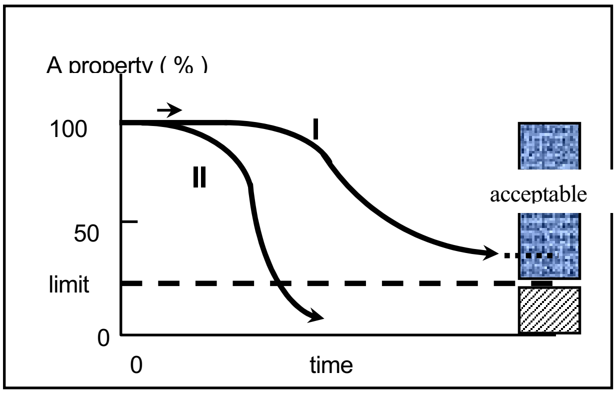


Figure-1 : Functional property variation with time

2. GEOTEXTILES

The durability of a geotextile depends upon it polymeric formulation and polymer microstructure, on any additives and fillers compounded with it, the fibre geometry and fabric layout. The geotextile should be chemically and biologically resistant if it is to be suitable for long term applications.

The polymers used to manufacture geotextiles are generally thermoplastic materials which may be amorphous or semi-crystalline. The orientation of polymers by mechanical drawing to form fibers and filaments results in higher tensile properties and improved durability. As the molecules become more oriented, the fibers become stronger. Durability of a textile may also be influenced by fiber diameter, and the volume to surface ratio: some means of degradation (oxidation and UV-exposure) are dependent on surface area and others (diffusion and absorption) are inversely related to thickness.

Any polymer consists of long chain molecules each containing many identical chemical units. Each unit may be composed of one or more monomers, the number of which determines the length of the polymeric chain and resulting molecular weight. Molecular weight can affect physical properties such as the tensile strength and modulus, impact strength, flexibility and heat resistance as well as the durability properties. The mechanical and physical properties of the plastics are also influenced by the bonds within and between chains, chain branching, and the degree of crystallinity.

Crystallinity has a strong effect on polymer properties, especially the mechanical properties, because the tightly packed molecules within the crystallites results in dense regions with high intermolecular cohesion and resistance to penetration by chemicals. An increase in the degree of crystallinity leads directly to an increase in rigidity, tensile strength, hardness and softening point, and to a decrease in permeability and gas diffusion. Neighbouring crystallites may be connected by single molecules running through the amorphous regions, which under tension make a significant contribution to the mechanical behaviour. These 'tie' molecules are, however, susceptible to chemical attack.

Geotextiles are available in a wide range of compositions appropriate to different applications and environments and the synthetic polymers used consist mainly of polyester (PET), polypropylene (PP), polyethylene (PE) and polyamide (PA).

Polypropylene (PP) is a thermoplastic long chain polymer normally used in the isotactic stereoregular form in which propylene monomers are attached in head-to-tail fashion and the methyl groups are aligned on the same side of the polymer backbone. PP has a semi-crystalline structure which gives to it high stiffness, good tensile properties and resistance to acids, alkalis and most solvents. It is possible for the tertiary carbon to react with free radicals, so that stabilizers are added to prevent oxidation during manufacture and generally to improve long term durability, including weathering.

Polyesters (PET) are a group of polymers and the type used most frequently in geotextiles is polyethylene terephthalate (PET) which is a condensation polymer of a dibasic acid and a di-alcohol. PET offers good mechanical properties, including a low creep strain rate, and good chemical resistance to most acids and many solvents. The ester group, the important polymeric link, can be hydrolysed very slowly in presence of water, and more rapid attack occurs under highly alkaline conditions. As with other polymers PET is sensitive to weathering.

Polyethylene (PE) is one of the simplest organic polymers and it is used in its low density form (LLDPE), which is known for its excellent pliability, ease of processing and good physical properties, or as high density polyethylene (HDPE) which is more rigid and chemically resistant. PE can be stabilized to increase its resistance to weathering.

Polyamides (PA) or nylons are melt processable thermoplastics that contain an amide group as a recurring part of the chain. PA offers a combination of properties including high strength at elevated temperatures, ductility, wear and abrasion resistance, low frictional properties, low permeability by gases and hydrocarbons, and good chemical resistance. Its limitations include a tendency to absorb moisture, with resulting changes in dimensional and mechanical properties, and limited resistance to acids and weathering. The PA fibres used in geotextiles have a T_g of 40-60 °C which reduces with moisture content. Nylons are sensitive to biochemical attack.

Recycled and reworked Materials: In the industry, three expressions are used to identify recycle of processed materials: *rework resin (RR) (or regrind), post-consumer resin (PCR) and post-industrial resin (PIR).* It is common practice within the plastics industry to recycle the processed material (in-house scrap polymer or rework resin), since it can be considered as comparable to virgin material as long as it is used in small percentages (less than 10%). Post-industrial resin (PIR) is the recycling of industrial resin originating from another process. The level of control over the quality of the material, and thus its durability, decreases with the number of stages and processes it has gone through after leaving the original manufacturer's plant. For severe environments and for long-term applications it is advisable not to use post consumer recycled polymer without proof of its long term durability. The composition of the polymer should be assured.

3. SOLLICITATIONS ON GEOTEXTILES

3.1. The environment below ground

Below ground the main factors affecting the durability of geosynthetics are as follows: particle size distribution of the soils and granular angularity (Figure-2); acidity/alkalinity (pH) - humates, sodium or lime soils, lime hydration, concrete; metal ions present; presence of oxygen; moisture content; organic content; temperature; and microorganisms. Chemical degradation of polymers occurs by a variety of processes including oxidation and hydrolysis, depending on the type of polymer and on the acidity or alkalinity of the soil. At higher loads, creep leads ultimately to creep-rupture, also known as stress-rupture or static fatigue: the higher the applied load, the shorter the lifetime.

hydrolysis : Polyester and polyamide fibers are susceptible to hydrolysis, which in polyester fibers takes two forms: the first, alkaline or external hydrolysis, occurs in alkaline soils above pH 10, particularly in the presence of calcium, and takes the form of surface attack and caution should be applied in the use of polyesters for long periods above pH 9; the second, internal hydrolysis, occurs in aqueous solutions or humid soil at all values of pH and it takes place throughout the cross-section of the fiber and the rate of hydrolysis is very slow, such that the process has little effect at mean soil temperatures of 15 ºC or below, although it can be accelerated in acids. Sensitivity to hydrolysis can be reduced by selecting a PE of sufficiently high molecular weight and with limited branching, characterized by a low carboxyl end group count. Cowland et al (1998) performed tests on 14 year old PET woven textile and a woven PP slit film textile samples from a wall located in Hong Kong: the PET lost 15% of its tear resistance while the PP maintains its original resistance.

Figure-2 : Photograph of attacked geotextile by aggressive cover soil

chemical attack: Chemical attack is most serious when the polymer chain backbone is broken. Acidity and alkalinity are expressed as pH, a scale with neutral soil having a pH of 7. Topsoil generally has a pH of 5.5 – 7 (acid soils) , but anaerobic peats or soils which have been affected by acid rain may have a pH of approximately 4. Atmospheric carbon dioxide leads to generally increased acidity at the surface. Limestone or chalk soils may have a pH of 8 - 8.5. Geological deposits have a wide range of pH with values between 2 and 10 having been recorded.

micro-biological attack: In the past 25 years there have been no reports of microbial attack on synthetic geotextiles either in testing or in the ground (Ionescu et al, 1982 – Leflaive et al, 1988 - Giroud, 1996). The long chain molecules of thermoplastics used in geotextiles are generally resistant to microbial attack. Also, low molecular components and certain additives could be susceptible to biodegradation, but this can be countered by bio-stabilizers. Only geotextiles containing vegetable fibers and containing fiber-glass scrims, are likely to be affected.

3.2. The environment above ground

Ageing of exposed geosynthetics is mainly initiated by the ultraviolet (UV) component of solar radiation, heat and oxygen, with contributions from other climatic factors such as humidity, rain, oxides of nitrogen and sulphur, ozone, deposits from polluted air and pollens, and contained liquids. In most applications geotextiles are exposed to UV light for only a limited time during storage, transport and installation and are subsequently protected by a layer of soil. On the other hand, exposed geotextiles, mainly installed at top of slopes of reservoirs, ponds and channels, must resist for a longer time. The need for either short or long term resistance to weathering therefore depends on the application. In addition, atmospheric pollution and acid rain may enhance UV degradation, particularly of PA, for longer exposures above ground.

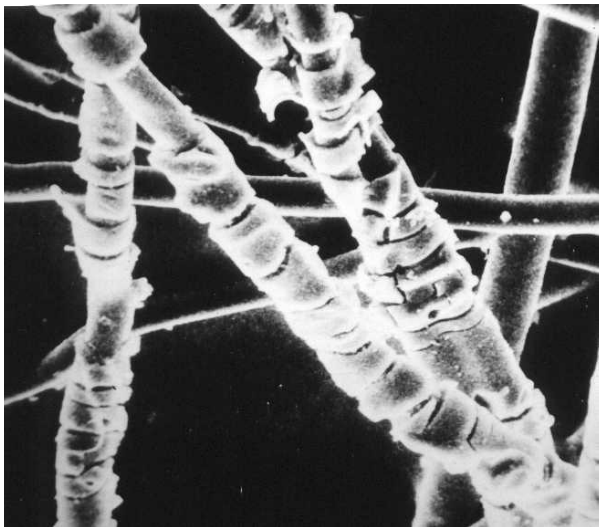


Figure-3 : Photograph of attacked geotextile by UV

ultraviolet radiation: The energy of ultraviolet radiation is sufficient to initiate rupture of the bonds within the polymer leading to subsequent recombination with, for example, oxygen in the air, or initiating more complex chain reactions. Additives increase resistance to ultraviolet radiation in a variety of ways, the most used being the carbon black. Geotextiles protected with an anti-oxidant can resist longer to the attack: few weeks for the PET and more for the PP and PE. Artieres et al (1998) showed that a PP non-woven geotextile installed on landfill cover in four sites did function well after 12 months even though it has loss 55% of its strenght. The resistance to ultraviolet radiation is affected both by the surface temperature of the sample and by precipitation, for which reason accelerated weathering tests include control of temperature and an intermittent spray cycle. UV radiation in the 400 to 280 nm range is responsible for degradation of geotextile fibers as shown in Figure-3. The photo-oxidation reaction can break chemical links (C-C or C-H) of the polymer chains and for each type of polymer a wavelength ca initiated the reaction: PE 300 nm, PET 325 nm and PP 370 nm.

oxidation : Polypropylene and polyethylene are susceptible to oxidation. This is accelerated by the catalytic effects of transition metal ions in a chemically activated state. Of these the ferric (Fe^{3+}) ion is the most common but copper and manganese have also been shown to be important. However, the sensitivity to oxidation is dramatically reduced by the inclusion of antioxidant stabilizers or additives and is retarded by the high level of orientation in polymer fibers as are found in most geotextiles. All chemical reactions occur more rapidly at higher temperatures, as described by Arrhenius' Law.

rodents and roots: Geotextiles in soil also come in contact with animals such as rodents and with the roots of plants. Rodents can locally destroy a geotextile while roots can penetrate and clog it. No specific tests have been proposed to simulate attack by rodents, while tests the susceptibility to penetration by roots have been developped.

mineral and bacterial clogging: mineral and bacterial clogging of geotextiles can drastically shorten the serfice life of a drainage system. The filling up of the textile void by soil particles (Rollin et al, 1988 et Giroud, 1996) or by biomass formation (Rollin et al, 1996 ; Rowe, 1998 and Giroud et, 1996) have been reported by many authors.

3.3. Tensile Load

A major difference between polymers and metals is that at normal operating temperatures and tensile loads, polymers extend with time, that is they creep. This was recognized early in the development of geotextiles and led to an increasing number of testing programs to provide the information necessary for the design of reinforced soil structures. Creep and creep-rupture should only be regarded as a relevant design criterion in slopes and walls when the geotextile is expected to perform a reinforcing function in the long-term, or in reinforcement over a soft foundation. Of equal importance is definition of the creep strain, which even at low loads may cause a reinforced soil structure to reach a serviceability limit by movement or sagging without leading to total collapse. At higher loads creep leads ultimately to creep-rupture, also known as stress-rupture: the higher the applied load, the shorter the lifetime. The load which, if applied continuously over the lifetime of the product, is predicted to lead to creep-rupture on the last day of the design life, is defined as the unfactored design load.

At the microscopic level, when a load is applied to a polymer, it will cause the long chain molecules to stretch or rearrange themselves. While the crystalline areas remain relatively stable under load, rearrangement takes place in the amorphous regions, and it is noticeable that in polymers such as PE and PP used above T_g , where the amorphous regions are in a rubbery rather than a glassy state, creep takes place more rapidly and is more sensitive to temperature than those such as PET used below T_g In oriented polymers an important part is played by the "tie" molecules which link one crystallite with another across the amorphous regions. For example, in PET molecules the load can cause these highly stressed molecules to change the arrangement of their side branches, resulting in a temporary reduction in secant modulus and in the characteristic S-shaped stress-strain curve. These processes of rearrangement continue under the combined effects of load and thermal activation.

4. EMPIRICAL EVIDENCE FROM RETRIEVED GEOTEXTILES

Will geotextiles last for 5, 50, 100 years or longer? To answer this question we should start by investigating empirically what has been established over the past 35 years. Some examples giving clear evidence of durability are given below (Sotton et al (1982), Delmas (1988), Leflaive (1988), Wisse et al (1992), Mlynarek (1994), Troots et al (1994), Rollin (1996) et Rowe (1998)).

During the period 1965-1980, Sotton et al reported on PET and PP non-woven samples retrieved from 25 sites in France, ten to fifteen years after installation. These fabrics were still functioning as filters, separators and drainage layers. Losses in tensile strength of up to 30% were observed, but with laboratory analysis no chemical or biological attack could be identified.

In the following decade 1980-1990, Leflaive reported on a 5 m high vertical wall in France, which had been constructed in 1970. In this case 5 m long PET straps had been embedded in the concrete facing elements and anchored in the backfill, which had a pH of 8.5. Testing of the straps after 17 years showed a 2% reduction in tensile strength in the backfill but up to 40% reduction at the point where the straps enter the concrete facing units. Here the pH value has believed to have reached 13 to 14 at a temperature of 30ºC for some time. Subsequent analysis showed that this degradation could be explained by alkaline surface attack (25%), internal hydrolysis (5-10%) and mechanical damage.

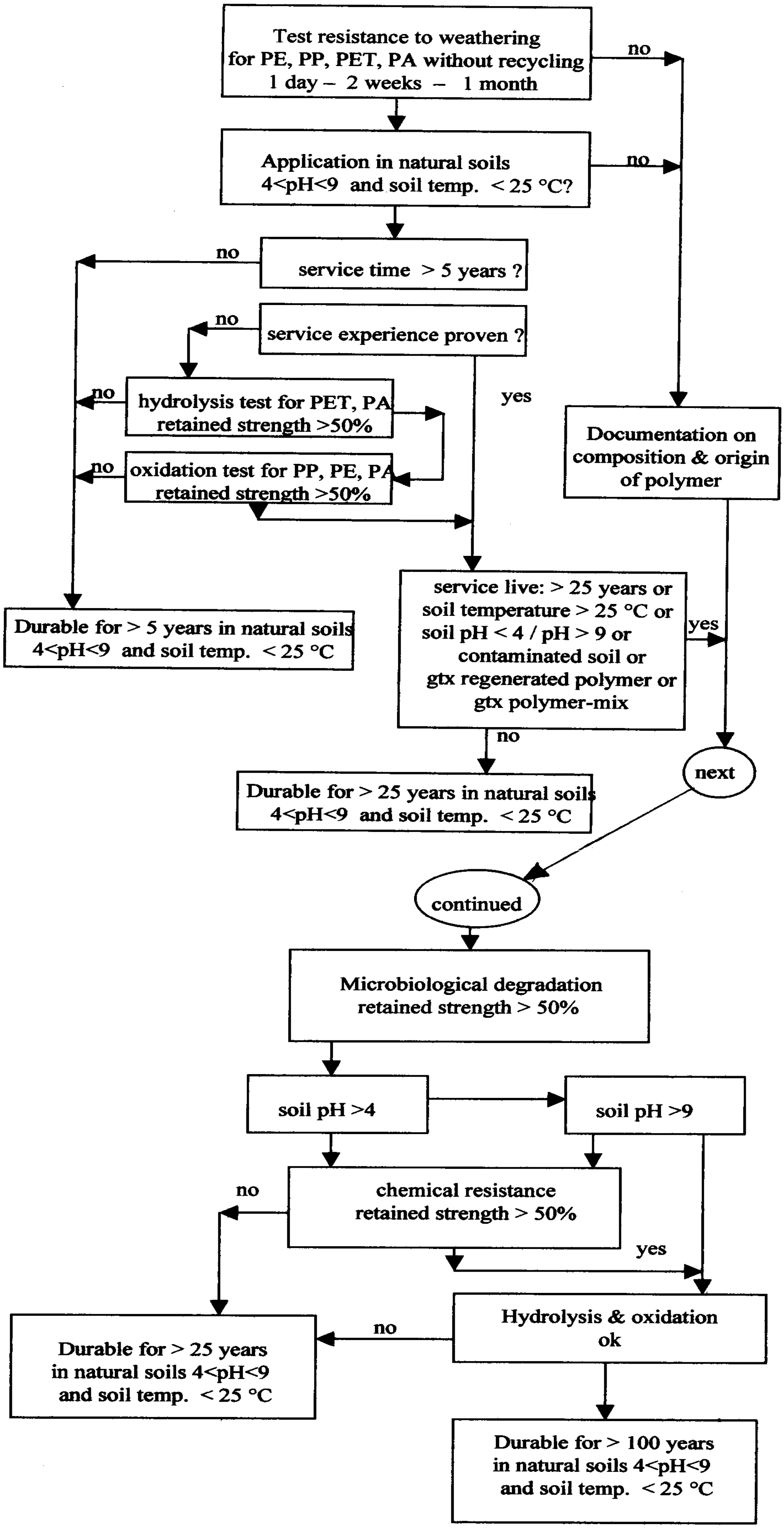
In 1990, Wisse et al reported on samples of 1000 g/m² woven PP, part of 4 Mm^2 that had been laid as the backing of block mattresses on the sea bed of the Oosterschelde in 1978 to prevent scouring. The fabric had been in sea water at 10ºC for 9 years with a local partial pressure of 3% oxygen. The permanent load was only 10% of the tensile strength. Retrieved samples were subjected to accelerated oven ageing and compared with unexposed samples from the original source of material: the estimated time to embrittlement in sea water at 10ºC was calculated to be 80-120 years.

In 1994, Troost et al reported on the condition of large quantities of woven PET fabric retrieved from a soil retaining structure. A multi-layered geotextile reinforced wall, 4 m high, with slopes of 2:1 and 4:1, was constructed in the Netherlands. Thirteen years later the wall was carefully dismantled and the mechanical and chemical properties of the yarns investigated. The 50 m long embankment had slopes partially covered with bitumen and vegetation to prevent ultraviolet attack. After the retrieved fabric had been tested no hydrolysis could be detected on material either from the interior of the embankment or from the protected slopes, i.e. the mechanical properties, molecular weight (M_W = 33000), and carboxyl end group count had not changed. On the unprotected slopes, a reduction of between 15% and 50% in tensile strength was observed, which was concluded to be due mainly to UV radiation.

5. CONCLUSION

Flow chart of the process of evaluation of durability of geotextiles is under development at the European Standard Committee (DIN EN 13249 Annexe E). A modified version is presented as a conclusion.

Note: For service life greater than 100 years, in the accompanying document the retained strength should be clearly identified: hydrolysis for PET and PA, oxidation for PP, PE and PA, stabilizer content for PE and PP


Test resistance to weathering
for PE, PP, PET, PA without recycling
1 day – 2 weeks – 1 month
no
Application in natural soils
4<pH<9 and soil temp. < 25 °C?
no
no
service time > 5 years ?
no
service experience proven ?
no
hydrolysis test for PET, PA
retained strength >50%
no
oxidation test for PP, PE, PA
retained strength >50%
yes
Documentation on
composition & origin
of polymer
Durable for > 5 years in natural soils
4<pH<9 and soil temp. < 25 °C
service live: > 25 years or
soil temperature > 25 °C or
soil pH < 4 / pH > 9 or
contaminated soil or
gtx regenerated polymer or
gtx polymer-mix
yes
no
next
Durable for > 25 years in natural soils
4<pH<9 and soil temp. < 25 °C
continued
Microbiological degradation
retained strength > 50%
soil pH >4
soil pH >9
no
chemical resistance
retained strength > 50%
yes
Hydrolysis & oxidation
ok
no
Durable for > 25 years
in natural soils 4<pH<9
and soil temp. < 25 °C
Durable for > 100 years
in natural soils 4<pH<9
and soil temp. < 25 °C

6. REFERENCES

Artières O., Gaumet S. and Bloquet C. 1998. Prediction of the UV Ageing of Polypropylene Geotextiles – Landfills case, proceedings 6th Conf. Geosynthetics, IGS, vol 1, pp 393-398

ASTM D 5819, 1998, Standard Guide for Selecting Test Methods for Experimental Evaluation of Geosynthetic Durability

Cowland J.W., Yeo K.C. and Greenwood J.H. 1998. Durability of Polyester and Polypropylene Geotextiles Buried in a Tropical Environment for 14 Years , proceedings 6th Conf. Geosynthetics, IGS, March, vol 2, pp 669-674

Delmas Ph., Faure Y., Farkouh B. and Nancy A. 1994. Long Term Behavior of a Geotextile as a Filter in a 24 year Old Earth Dam : Valcros, proceedings 5th Conf. Geosynthetics, IGS, Singapore, pp 1199-1202

Giroud J.P. 1996. Granular Filters and Geotextile Filters, proceedings Geofilters'96, Montreal, pp 565-680

Koerner R.M., Lord A.E. and Hsuan Y.G. 1988. Long-Term Durability and Ageing of Geotextiles», Geotextiles and Geomembranes, vol 7, pp 147-158

Koerner R.M., Lord A.E. and Hsuan Y.G. 1992. Arrhenius Modeling to Predict Geosynthetic Degradation, Geotextiles and Geomembranes, vol 11, pp 151-183

Ionescu A. et al 1982. Methods Used for Testing the Bio-Colmatation and Degradation of Geotextiles Manufactured in Romania, proceedings 2nd Conf. Geotextiles, IFAI, pp 547-552

ISO 13434 (1997), "Guide to durability of geosynthetics", under revision

Leflaive E. 1988. Durability of Geotextiles : the French Experience , Geotextiles and Geomembranes, vol 7, pp 23-31

Mlynarek J., Bonnell R.B., Broughton R. and Rollin A.L. 1994. Long Term Effectiveness of Geotextiles on Subsurface Agricultural Drainage Systems, proceedings 5e Conf. Int'l Geotextiles, IGS, Singapore, pp 949-952

Rollin A.L. and Lombard G. 1988. Mechanisms Affecting Long-Term Filtation Behaviour of Geotextiles, Geotextiles and Geomembranes, vol 7, pp 119-145

Rollin A.L. 1996. Bacterial Clogging of Geotextiles, proceedings Geofilters'96, Montréal, pp 125-134

Rowe, R.K. 1998. Geosynthetics and the Minimization of Contaminant Migration through Barrier Systems Beneath Solid Waste, proceedings 6th Conf. on Geosynthetics, IGS, pp 27-102

Sotton M, Leclercq B, Paute J L and Fayoux D. 1982. Some answer's components on durability problem of geotextiles, Proceedings 2nd Conf. Geotextiles, Vol 2, Las Vegas, pp553-558

Troost G H , den Hoedt G, Risseeuw P, Voskamp W. and Schmidt H M 1994. Durability of a 13 year old embankment reinforced with polyester woven fabric, 5th International Conference on Geotextiles, Geomembranes and Related Products, Singapore, IGS, pp1185-1190

Wisse J.D.M., Broos C.J.M. and Boels W.H. 1990. Evaluation of the life expectancy of polypropylene geotextiles used in bottom protection structures around the Ooster Schelde Storm Sturge Barrier - A Case Study, 4th Conf. Geosynthetics, The Hagen, Netherlands, pp 697-702