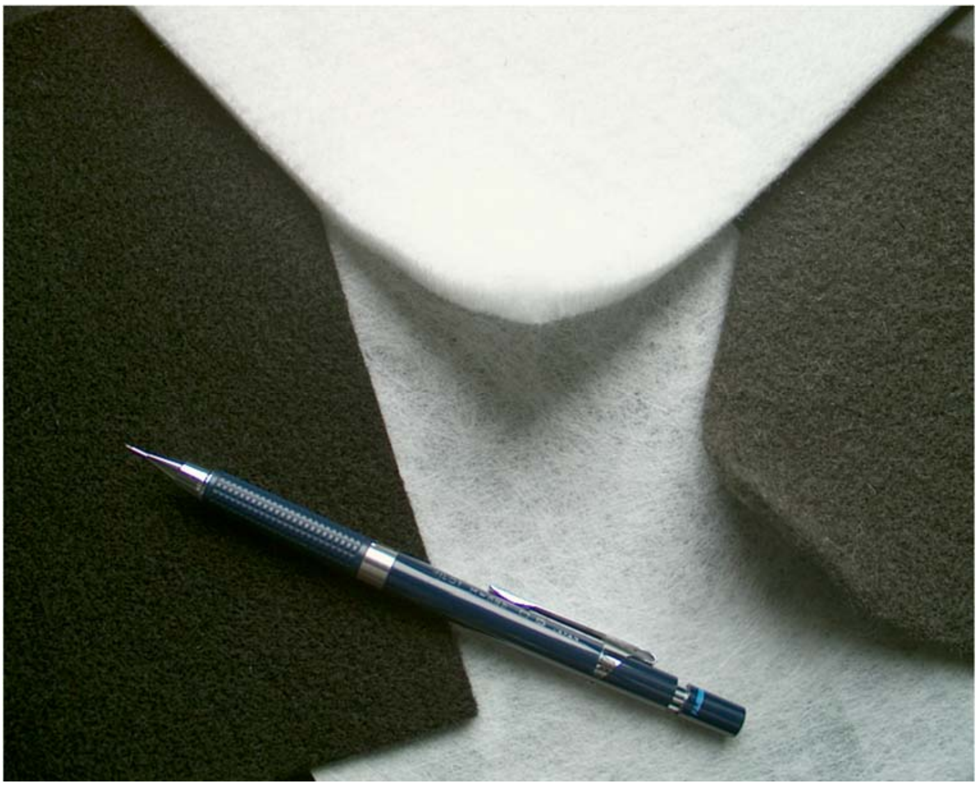
The durability of geotextiles



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Introduction

Initial consideration

Geotextiles used in civil engineering applications are expected to carry out one or more functions over a given design life. There are five defined functions[1], these are; drainage, separation, filtration, protection and reinforcement. The functional requirements of the geotextile in a given application will determine the performance properties required, and any assessment of the products durability will be based on the degradation of these properties over a given time.

There are a number of factors that will help to determine the durability of a geotextile; the physical structure of the fabric, the nature of the polymer used, the quality and consistency of the manufacturing process, the physical and chemical environment in which the product is placed, the condition in which the product is stored and installed and the different loads that are supported by the geotextile.

It is essential that a geotextile performs effectively for the required duration of the design (many being in excess of 100 years), and not just in initial conformance testing.

This report is intended to provide guidance on selecting the appropriate geotextile for a given application in relation to long term product durability and 'lifetime prediction'. It will explain the steps taken by GEOfabrics to ensure that its product range meets the highest possible standards.

Raw material selection

Geotextiles are normally manufactured by either woven or non-woven techniques, the polymers used are generally thermoplastic materials which contain variations of both amorphous and semi-crystalline regions.

The GEOfabrics product range is manufactured from needle-punching polypropylene staple fibre[2]. The fibre that is used by GEOfabrics is sourced from a limited number of suppliers, all of which have been through a lengthy approval process and ongoing auditing to an ISO 9001 framework to ensure that the material consistently meets very stringent specification criteria.

There are several factors relating to fibre selection that must be considered in relation to end product durability; the basic polymer from which the product is made, any additives compounded with it, and the fibre morphology. Fibre morphology in materials science relates to the science of form and is linked to all physical aspects of the polymers structure.

GEOfabrics HPS range is manufactured from high tenacity virgin polypropylene fibre which is mechanically drawn to form fibres with higher tensile properties and improved durability. The increased drawing within the fibre manufacturing process re-orientates the molecules within the fibre making it stronger. The increased molecular orientation and associated higher density leads to increased environmental resistance. This is because the level of crystallinity within the fibre has a large effect on the properties relating to durability[3]. The tightly packed molecules result in dense regions with higher intermolecular cohesion and resistance to penetration by chemicals. An increase in the degree of crystallinity leads directly to an increase in rigidity and yield or tensile strength, hardness and softening point, and decrease in chemical permeability[4].

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1 ISO 10318 – Geosynthetics: Terms and definitions.
2 Staple fibre means that the individual fibres within the product have been cut to a specified length prior to the manufacturing
3 Where molecular chains are kinked, randomly orientated and often entangled, the configuration of the polymer region is said to be amorphous. Where molecular chains are more closely packed, taking a more regular form, the polymer region is said to be crystalline. Most polymers contain both amorphous and crystalline regions.
4 ISO 13434:1998 – Guidelines on durability of geotextiles and geotextile related products.

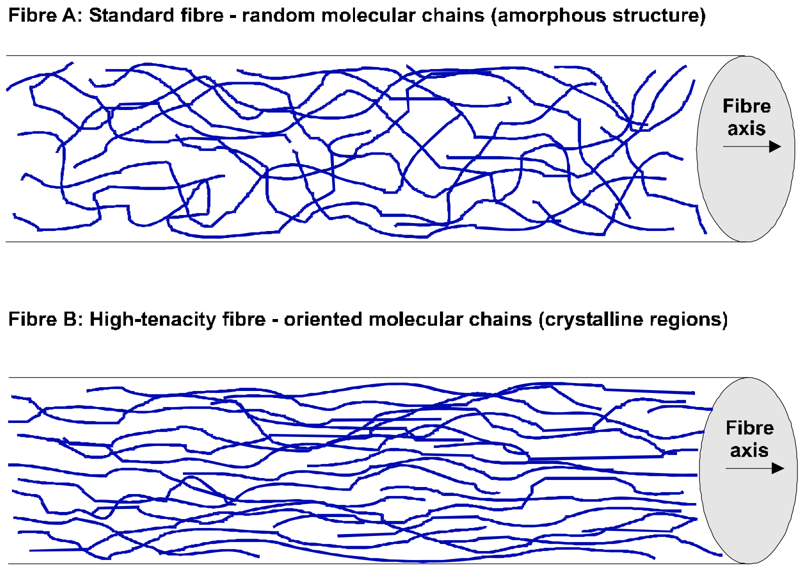


Figure 1: Improved molecular orientation of high-tenacity fibres

Low-cost fibre is also available within the market, usually as a by-product of another manufacturing process such as carpet making; designed for aesthetics rather than performance. These fibres will be of mixed origin and can therefore have inconsistent properties, moreover the performance consistency and hence the quality of the resultant geotextile will be inferior to those produced from prime quality virgin fibre made to a controlled specification.

The fibre morphology in such products will be inconsistent from batch to batch as the fibres may be sourced from multiple types and colours. The ratio of amorphous and crystalline regions can vary from batch to batch as the fibres are not of one type. The variation in pigmentation will also have an effect on the level of crystallinity within the polymer and thus the level of attack that the fibre can be susceptible to[5].

Fabrics can be produced from both industrial and post-consumer recycled fibres. Such fibre types can be of different thicknesses, and volume to surface ratios. Some types of degradation, such as oxidation and UV-exposure, are dependent on surface area, whilst others such as diffusion and absorption are inversely related to thickness.

The selection of the right polymer type for the manufacture of textiles for use in civil engineering applications is essential. GEOfabrics HPS range is manufactured from virgin polypropylene fibres which have a high resistance to acids, alkalis and most solvents. Polypropylene can be considered as inert to acid and alkali attack and is suitable for most geotextile applications. Polypropylene can be susceptible to oxidation, however oxygen levels are normally low below soil level and GEOfabrics perform on-going oxidation tests to ensure accurate assessment of oxidation rates in relation to long term durability (reviewed later in report).

Another polymer fibre that is used within Geotextile manufacturing is polyester, of which the most common type is polyethylene-terephthalate (PET) which is produced using condensation polymerisation. Polyethylene terephthalate is made by condensing ethylene glycol with either terephthalic acid itself or with dimethyl terephthalate (see Figure 2).

5 Morphology of the non-coloured and coloured polypropylene fibres – Institute of Textile Engineering and Polymer Materials, University of Bielsko-Bia a, ul. Willowa 2, Bielsko-Bia a 43-309, Poland

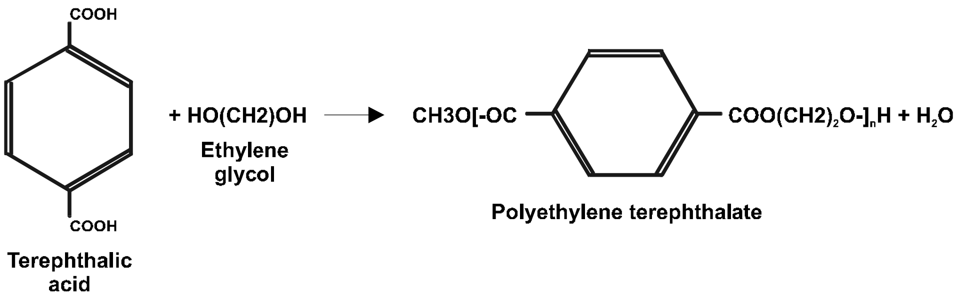


Figure 2: Production of PET

PET can offer good mechanical properties and is suitable for some applications; however the ester group can be hydrolysed in the presence of water[6], which is accelerated by alkaline conditions. Polyester can also be susceptible to heightened degradation where there is lime treated soil, concrete or cement present[7].

Hydrolysis in polyester takes two forms. The first form of hydrolysis is alkaline or external hydrolysis which occurs more rapidly in soils above pH 10, and particularly in the presence of calcium, and takes place in the form of surface attack, or etching. Increased caution should be taken with polyester in soils with pH 9 or above[8]. The second type is internal hydrolysis which takes place across the entire cross section of the fibre, this occurs in aqueous solutions or humid soil at all pH levels. This process is slow in mean soil temperatures of <15°C or neutral soils, however this is accelerated in acids and increased soil temperatures.

Although polyester can have advantages over other polymers the alkaline sensitivity of this polymer under long-term loadings should be a major concern in many geotextile applications, polyester can be susceptible to damage in high pH applications. An independent study conducted by the University of Leeds showed that '*If the conditions are slightly alkaline, the combined action of load and alkali could be catastrophic and the use of polyester would have to be restricted'*[9].

Standards for durability testing - requirements for CE marking

Since the late 1980's the CEN TC 189 committee has standardised testing methods and procedures to encourage continuity and consistency across the industry. Since the early part of 2002 it has become a mandatory requirement to CE mark geotextile and geotextile related products to demonstrate compliance with the European construction products directive.

The main aim of the construction products directive is to break down technical barriers to trade in construction products between Member States in the European Economic Area. To achieve this it provides for four main elements:

- a system of harmonised technical specifications
- an agreed system of attestation of conformity for each product family
- a framework of notified bodies
- the CE marking of products

The construction product directive does not aim to harmonise regulations, what it aims to do is harmonise the methods of testing and the way in which manufacturers of products report on their performance values, and the method of conformity assessment.

The CE marking is a 'passport' that enables a product to be legally placed on the market within any member state. *CE marking does not mean that the product is suitable for an end use*, it simply means that the manufacturer has complied with the regulations set out within the CPD and that it must report on the harmonised declared values set out within the standards.

For geosynthetics, there are several standards published by CEN TC 189 for CE marking based on product applications, these are:

6 Hydrolysis is a reverse reaction of the initial condensation polymerisation used to produce PET. Condensation
7 Broken concrete is generally between pH 11-13, lime marl between pH 10-11 (CEN-Bericht 13434-2000, Table 2 & Kuntze et al)
8 ISO 13434:1998 – Guidelines on durability of geotextiles and geotextile related products.
9 The alkaline degradation of polyester geotextiles - Dr. Mashiur Rahman; Univ. of Leeds Department of Textile Industries 1997 – Also published within GEOQuebeq 2004.

EN 13249:	**Geotextiles for roads and other trafficked areas**
EN 13250:	**Geotextiles for railways**
EN 13251:	**Geotextiles for earthworks, foundations and retaining structures**
EN 13252:	**Geotextiles for drainage systems**
EN 13253:	**Geotextiles for erosion control works**
EN 13254:	**Geotextiles for reservoirs and dams**
EN 13255:	**Geotextiles for canals - Intended uses**
EN 13256:	**Geotextiles for tunnels and underground structures**
EN 13257:	**Geotextiles for solid waste disposal**
EN 13265:	**Geotextiles for liquid waste disposal**

The testing that needs to be performed on a product depends on the function that the product is required to perform within the application. The functions are based on the five functions that are set out within ISO 10318 as described earlier

The levels of control within the manufacturing process are audited by the accrediting body – GEOfabrics use BTTG certification for this. The manufacturer is then issued with a certificate of factory production control under the guidelines identified within the EN application standards.

Within Annex B of the standards, there is guidance on the testing that is required in order to make an assessment of the long-term durability of the product. For Polypropylene geotextiles the tests that are required are:

Determination of resistance to weathering (UV)	**EN 12224 (2000)**
Determining the resistance to liquids (acids & alkalis)	**ISO 12960 (2000)**
Determination of resistance to oxidation	**EN 13438 (2000)**
Resistance to microbiological attack by soil burial	**EN 12225 (2000)**
Procedure for simulating damage during installation[10]	**EN 10722 (1998)**

Following a factory inspection to verify procedures and a further inspection of records and equipment calibration – GEOfabrics have obtained a CE mark for all of its HPS geotextile range.

Resistance to weathering

Geosynthetic products can be exposed to weathering and the resulting effect on the performance of products is of importance. The ageing of geotextiles in predominately set in motion by the climate effects through the presence of solar radiation, heat, wetting and moisture.

Geosynthetics are normally exposed to weathering for a relatively short but somewhat varying time during construction work. The properties of unprotected polymers with are such that just one week of outdoor exposure can seriously damage the geotextile[11]. The mechanism of degradation in most polymers is photochemical in nature, the absorption of ultraviolet light by the polymer provides the energy to break key molecular bonds near the surface of the exposed plastic. The resultant free radicals then react with oxygen to form peroxy radicals which will attack other polymer molecules, or even other points within the same polymer chain. More free radicals are then formed resulting in a chain reaction along the duration of the polymer chain. Consequently, polymers used in geosynthetics must be protected by appropriate additives to minimise the detrimental effects of exposure to ultraviolet light energy.

GEOfabrics HPS range contains fine grade carbon black additive for ultraviolet light stabilisation. This is mixed in the polymer prior to the point of extrusion to allow for homogenous dispersion within the product. Carbon black acts as a strong UV absorber.

Natural weathering processes require testing over very lengthy durations and test replication is impractical, it is therefore desirable for practicality to use an accelerated method of testing to simulate the effects of natural weathering in a controlled environment using an artificial light source. This type of testing produced

10 Not part of harmonised testing (H); considered relevant to conditions of use (A)
11 Prediction of the weathering resistance of Geotextiles: Hufenus, Trubiroha and Schröder, BAM Berlin.

comparable data which can be used to accurately compare products. The principle of testing is to expose the product to simulated solar ultraviolet light for different radiant exposures with controlled cycles of temperature and moisture.

The guidance within the standards for CE marking dictates that unless products are to be covered on the day of installation, they should be tested in accordance with EN 12224 - Determination of resistance to weathering. This European test is an index test for determining the resistance of geosynthetics to weathering conditions more intense than those of natural weathering and allows differentiation between products which have little or no resistance to those which do have such resistance.

The method of the test is such that specimens of material to be tested are exposed to a light source for a defined radiant exposure and at recommended temperature and moisture conditions. After this exposure the change in performance is determined. In order to eliminate (as much as practically possible) the potential variation from one machine to another weathering processes must be represented as a function of the radiant exposure in MJ/m^2 (energy per surface). European standard EN 12224 exposes specimens to a continuous UV radiant exposure of 50 MJ/m^2; this is combined with a wet dry cycle of one hour spraying at a black standard temperature of 25±3 ˚C and five hours drying at a black standard temperature of 50±3 ˚C. 50MJ/m^2 is between 1.5 – 5 months of natural weathering in central Europe. The variation is due to the changing weather conditions from year to year. Research conducted by the BAM laboratory in Berlin was conducted during the 1990's to validate the EN 12224. Table one shows the significant level of variation of radiant exposure in Berlin and Bandol (Southern France). It is for this reason that it is extremely difficult to place product guarantees on products that do refer to natural conditions rather than MJ/m^2 of radiant exposure.

Natural weathering station	Radiant exposure λ (wavelength) < 400nm	Duration (days)	Season
Berlin	28 MJ/m^2	134	Winter 94/95
	44 MJ/m^2	59	Spring 95
	72 MJ/m^2	76	Summer 95
	147 MJ/m^2	182	Spring/Summer 95
	176 MJ/m^2	317	Autumn 94 to Autumn 95
Bandol	154 MJ/m^2	147	Spring/Summer 95

Table 1: Specification of the natural weathering tests in Berlin and Bandol[12]

In 2002 GEOfabrics performed comparative UV testing to EN 12224[13]. Figure 3 shows a significant difference in the reduction in performance between the HPS and MPS range of products. The MPS range loses up to 70% strength while the HPS range loses a maximum of 16% with most of the range limited to only a 10% strength. This is explained by the presence of carbon black (added for UV protection) in the HPS range, which is not added to the MPS range of products. The percentage loss in mechanical performance is reduced with increasing thickness, and hence the percentage of the product influenced by UV reduces.

12 Trubiroha, P., Schröder, H. (1997) Klassifizierung von Geotextilien hinsichtlict der Wetterbeständig-keit. – 5 Informations – und Vortragsveranstaltung űber Kunstoffe in der Geotechnik, Műnchen. Natural weathering was performed to ISO 877: 994 Method A on the roof of a 40mtr building in Berlin and a natural weathering test station in Bandol, Southern France. The angle of exposure was 45˚.
13 Ref: GEOfabrics durability test data D1/D2 – Report N°. R-020823-06

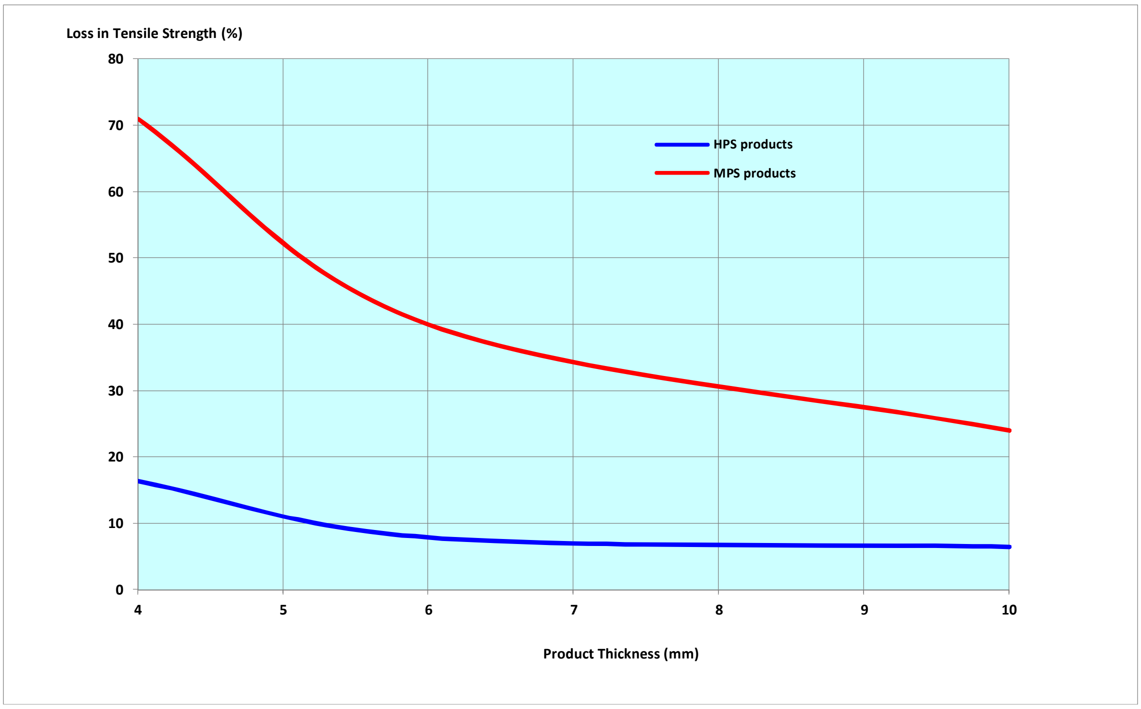


Figure 3: Loss in strength of protected and unprotected PP fibres after weathering

GEOfabrics HPS products are manufactured using a needle-punching process; they are mechanically entangled and receive no thermal finishing. This gives them excellent thickness to weight ratios, as the degradation process due to weathering starts at the surface[14]; they will generally perform better than similar products with low thickness values.

As part of the ongoing product assessment for CE marking a weathering test was performed by BTTG laboratories on GEOfabrics HPS 3 in Feb 2009[15]. The test was conducted in accordance with EN 12224:2000.

A Q-panel accelerated weathering tester was used which applied a total radiant exposure of 50 MJ/m^2 over a total exposure time of 350 hours. The test cycles over 6 hours with 5 hours dry light exposure at a black standard temperature of 50± 3˚C and 1 hour water spray at a black standard temperature of 25± 3˚C. The equipment incorporates a solar eye which maintains the correct irradiance automatically with UV intensity being monitored via four sensors at the sample plane. On completion of the test tensile tests were conducted on the material and assessed against control samples.

The results shown in table 2 highlight that HPS 3, one of the lowest grades in the HPS product range has excellent resistance to weathering. HPS products that are thicker than this will inevitably have improved performance.

	Control		Exposed			
	Tensile strength (N)	**Extension % @ max. load**	**Tensile Strength (N)**	**Extention % @ max. load**	**% retained strength**	**% retained extension**
MD						
Mean	**699.20**	**92.6**	**688.90**	**79.9**	**98.53**	**86.26**
SD	**70.82**	**4.20**	**36.47**	**2.51**		
CV	**10.13**	**4.53**	**5.29**	**3.14**		
CMD						
Mean	**1230.06**	**88.3**	**1143.56**	**75.1**	**92.97**	**85.05**
SD	**32.70**	**1.59**	**54.07**	**1.87**		
CV	**2.66**	**1.80**	**4.73**	**2.49**		

Table 2: EN 12224:2000 - GEOfabrics HPS 3 test results. Feb 2009

14 Prediction of the weathering resistance of Geotextiles: Hufenus, Trubiroha and Schröder, BAM Berlin.
15 Test report dated 02nd Feb 2009 – BTTG Ref: 10/13356/CA

As a guideline for assessing the weathering resistance of a product outside Europe and in relation to EN 12224 it is possible to use a global radiation map. Figure 4 shows a generalised guideline view of the isolines of global radiation expressed in kilolangleys of exposure per annum (Kcal/cm^2/yr).

1 kilolangley equates to 41.84 MJ/m^2 of the complete spectrum, however we are specifically concerned with the ultraviolet part of the spectrum. The ultraviolet part of the spectrum (<400nm) is approximately 7% of total solar radiation. On this basis 1 kilolangley equates to 2.93 MJ/m^2 radiant exposure.

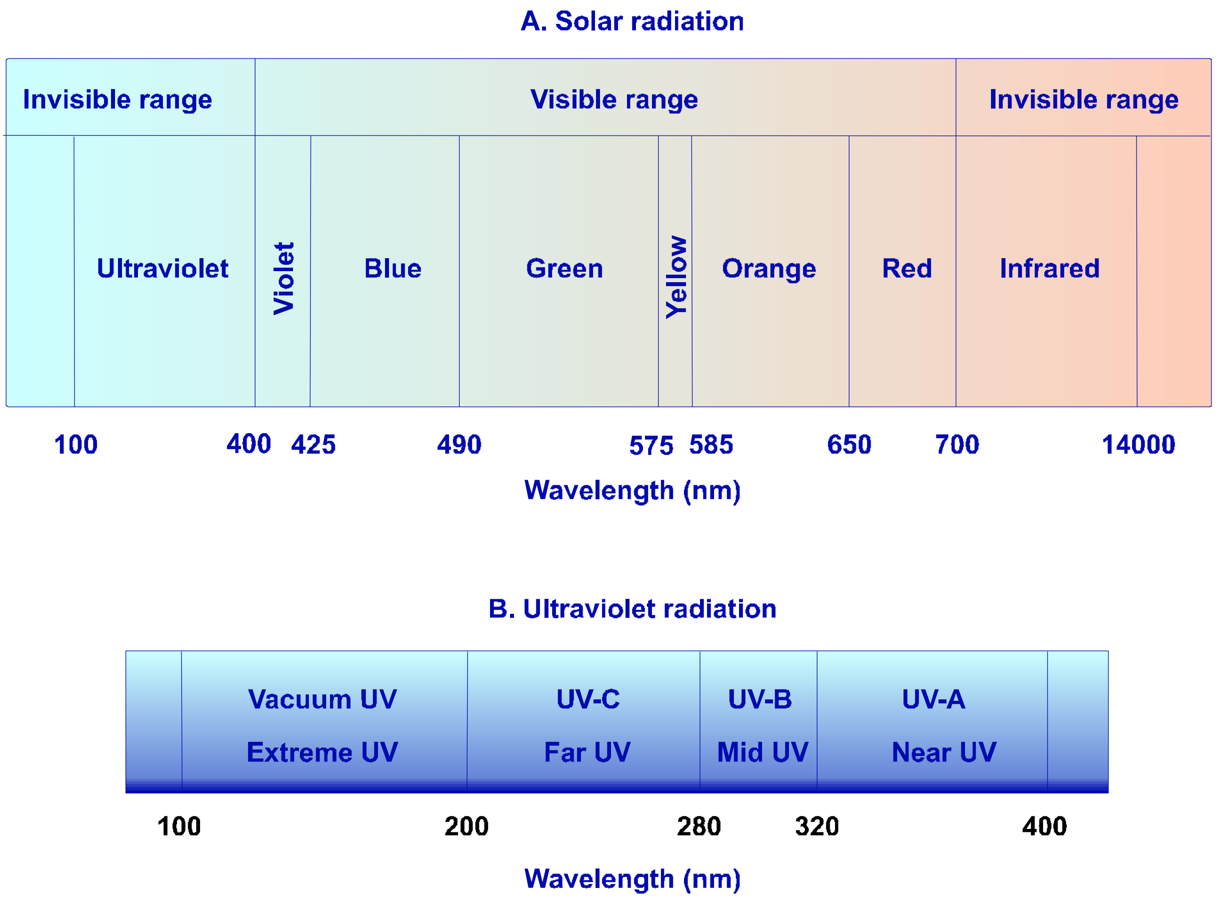


Figure 4: Solar radiation spectrum

If we use the map in Figure 5 we can make some basic assumptions about the products ability to withstand natural weathering in global locations.

For example from fig.5:

Northern Spain = 120 kilolangleys of global radiation per annum
120 kilolangleys = 5020.8 MJ/m^2 total exposure.
(5020.8/100) x 7 = 351.456

= **351.456 MJ/m^2 radiant exposure (UV) per annum**

= **29.288 MJ/m^2 average radiant exposure (UV) per month**

and

Central Australia = 180 kilolangleys of global radiation per annum
180 kilolangleys = 7531.2 MJ/m^2 total exposure
(7531.2/100) x 7 = 527.184

= **527.184 MJ/m^2 radiant exposure (UV) per annum**

= **43.932 MJ/m^2 average radiant exposure (UV) per month** and

Middle East = 220 kilolangleys of global radiation per annum
220 kilolangleys = 9204.8 MJ/m^2 total exposure
(9204.8/100) x 7 = 644.336

= **644.336 *MJ/m^2 radiant exposure (UV) per annum***

= **53.694 MJ/m^2 average radiant exposure (UV) per month**

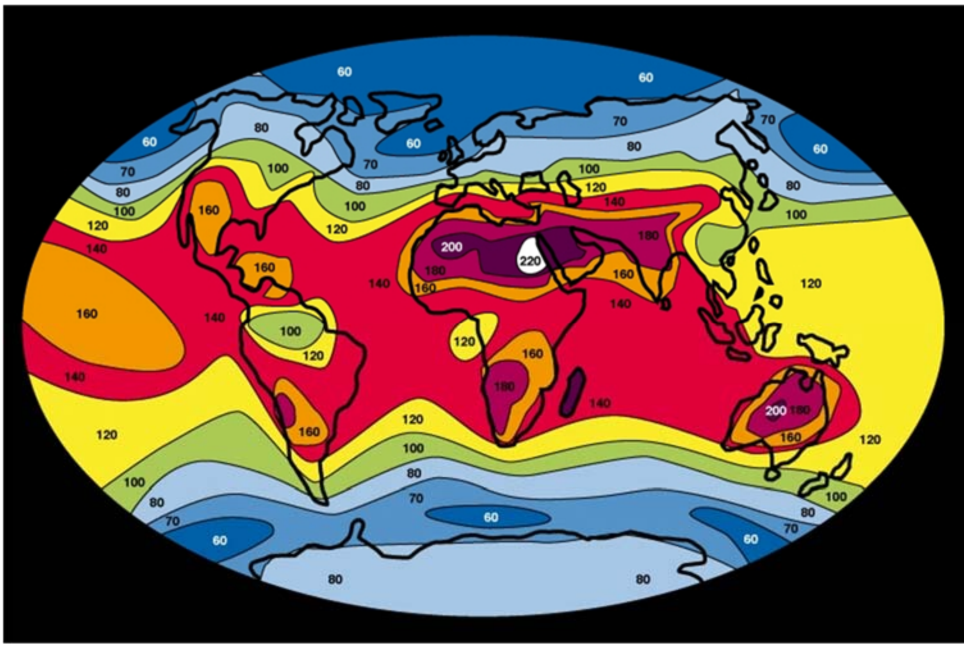


Figure 5: Generalised Isolines of global radiation expressed in Kilolangleys per annum (Kcal/cm2/yr)

It is important to remember that this calculation does not account for seasonal variation, which can be significant. However, it does highlight the need for a geotextile that has been designed to withstand UV attack. If we look at the performance of a geotextile without UV protection, we can clearly see that in some parts of the world, it could be a matter of weeks or even days before a catastrophic failure in mechanical performance occurs.

It must also be remembered that the MPS products are manufactured with fibres produced to a tightly controlled specification, with control of fibre diameter, draw ratio and polymer formulation. This is therefore the best case scenario for fabrics manufactured without UV protection; products manufactured from fibres that are not to a controlled specification could potentially have a much poorer performance.

Before selecting an appropriate geotextile for an application, the level of weathering that the product may be subjected to pre, during and post installation must be considered. The location and duration of exposure can drastically affect the physical and mechanical performance of the polymer. Geotextiles with appropriate additives must be selected to match the application conditions.

Resistance to liquids (acids & alkalis)

In nearly all civil engineering applications geotextiles can be in contact with aqueous solutions of acids, bases or dissolved oxygen. The resistance of geotextiles to these chemicals is a product of polymer formulation, manufacturing parameters, and fabric structure. External influences may also affect product performance, such as existing damage, liquid composition and in situ conditions such as temperature, pressure and mechanical stress.

Below the ground the main factors influencing durability are[16]:

- Particle size distribution and angularity of the soil
- Acidity/alkalinity (pH) – humates, sodium or lime soils, lime hydration, concrete, metal ions present
- The presence of oxygen
- Moisture content
- Organic content
- Temperature

ISO 13434 – Guidelines on durability identifies typical pH values of minerals and fills, it also notes *that the use of bentonite and other clays in civil engineering construction, such as diaphragm wall construction, grouting processes, sealing layers in landfill and tunnelling causes local areas of high alkalinity between pH values of 8,5 to 10*. Also, soils treated with lime (calcium hydroxide) can have pH values as high as 11. Concrete substrates also have high alkalinity (pH 11).

Minerals & fills	Formula	Maximum pH
Felspar		
Albite	**$NaAlSi_3O_8$**	**9 – 10**
Anorthite	**$CaAl_2Si2O_8$**	**8**
Orthoclase	**$KAlSi_3O_8$**	**8 – 9**
Sand		
Quartz	**SiO_2**	**7**
Muscovite	**$KAl2(OH,F)_2AlSi_3O_{10}$**	**7 – 8**
Clay:		
Kaolinite	**Al4(OH)8Si4O**	**5 – 7**
Carbonate:		
Dolomite	**$CaMg(CO_{3)2}$**	**9 – 10**
Calcite	**$CaCO_3$**	**8 – 9**

Table 3: Typical minerals and fills - pH values

GEOfabrics HPS and MPS product ranges are manufactured from virgin polypropylene fibres. Polypropylene fibres have a high resistance to acids and alkalis in all concentrations, and up to comparatively high temperatures. Polypropylene fibre is inherently inert but can be susceptible to oxidising agents; however the rate of attack is extremely slow on fibres that have been manufactured to appropriate specifications (see Oxidation).

EN 14030:2001 is an index test used as a method of screening geotextiles for resistance to liquids with specific pH values. As part of the ongoing product assessment for CE marking this test was performed by BTTG laboratories on GEOfabrics HPS 3 in Feb 2009[17]. Five specimens in each direction were immersed in the test liquids at a temperature of 60± 1˚C for a period of three days. The test liquids used were:

- An inorganic acid: 0.025 M sulphuric acid with 1mMol ferric sulphate and 1 mMol ferrous sulphate added.(Approximate pH 1.5)

- An inorganic base: calcium hydroxide ($Ca(OH)_2$), used as a saturated suspension. (Approximate pH 12.1)

Post exposure the specimens were rinsed thoroughly in accordance with the standard. The control specimens were immersed in water at 60± 1˚C for one hour. The specimens were then dried before tensile tests were conducted to assess performance.

Table 4 shows the results of testing performed in early 2009 on GEOfabrics HPS 3. As we can see from the results, the product experienced virtually no loss in tensile strength. The increase in tensile strength, and subsequent CMD decrease on the acid test, can be attributed to primarily to low sample variation. This highlights the high level of performance of polypropylene fibres in liquids with extreme pH levels (note that earlier testing on the MPS products showed similar results).

16 ISO 13434
17 Test report dated 02nd Feb 2009 – BTTG Ref: 10/13356/CA

Acid	Control		Exposed			
	Tensile strength (N)	Extension % @ max load	Tensile strength (N)	Extension % @ max load	% Retained strength	% Retained extension
MD						
Mean	1020.86	87.8	1067.88	91.2	108.73	97.41
SD	143.53	7.39	45.85	9.68		
CV (%)	14.06	8.42	4.29	10.62		
CMD						
Mean	1137.52	107.6	1142.34	102.0	96.98	92.24
SD	52.67	5.81	97.97	3.23		
CV (%)	4.63	5.40	8.58	3.16		

Alkali	Control		Exposed			
	Tensile strength (N)	Extension % @ max load	Tensile strength (N)	Extension % @ max load	% Retained strength	% Retained extension
MD						
Mean	1020.86	87.8	1055.96	92.4	107.19	99.11
SD	143.53	7.39	91.93	3.38		
CV (%)	14.06	8.42	8.71	3.66		
CMD						
Mean	1137.52	107.6	1065.58	97.6	104.96	105.61
SD	52.67	5.81	88.90	5.81		
CV (%)	4.63	5.40	8.34	5.96		

Table 4: Resistance to Liquids - EN 14030 - Alkali (pH 12.1) & Acid (pH 1.5)18

Resistance to oxidation

Oxidation is the reaction of the polymer, specifically polypropylene and polyethylene, with oxygen that can lead to the degradation of performance properties. The resultant outcome of the process of oxidation can be embrittlement, surface cracking, discolouration and most importantly reduction in molecular weight leading to a consequential loss in mechanical strength. Oxidation is a chain reaction started by free radicals normally produced by energising radiation (photo-oxidation) or heat; *this takes place in the amorphous regions of the fibre*.

Effectively designed antioxidant packages can be added to the fibre to significantly reduce the rate of oxidation. These will prevent the chain reaction in a number of ways and increase the lifetime of the product to an extent where it will outlive the duration of the design life. The degradation of polymers has been sub-divided into three stages: i) the reaction with surplus antioxidant within the polymer, ii) the consumption of the antioxidant and iii) the degradation of the unprotected polymer.

Polypropylene geotextiles are supplied in a wide variety of structures, the structure of the polymer and the additives within the fibre play a key role in the rate at which the material will oxidise. Antioxidants can be lost prematurely by migration, evaporation, leaching and may be deactivated by other additives or by incompatibilities arising in the polymer compound[19]. For long-term durability with a known rate of oxidation it is essential that a geotextile is manufactured from fibres produced to a controlled specification under consistent manufacturing conditions. Fabrics manufactured from fibres with inconsistent diameters, different pigmentations and additive packages cannot guarantee a level of durability. This is because even if a product is tested, the level of variation within the material is too great to ensure that the rate of oxidation is consistent.

As discussed earlier, GEOfabrics HPS range is manufactured from high tenacity virgin polypropylene. The fibre is manufactured to controlled diameters, with a draw ratio giving a high level of molecular crystallinity.

For CE marking of Geotextiles there is an accelerated test for the evaluation of the rate of oxidation of polyolefin materials. EN ISO 13438 is a screening test whereby test specimens are exposed to an elevated temperature in air over a fixed time period, using a regulated laboratory oven without forced air circulation. For polypropylene in non-reinforcement applications the temperature of the oven is 110 ± 1 ˚C and is maintained for a period of 14 days (i.e. 25 years equivalent) or 28 days for reinforcement, the tensile strength retained after completion of the test must exceed 50%. After the fixed period of oven aging the exposed

18 The apparent increase in tensile strength should be attributed to low level variation in sampling rather than a resultant property change due to the test.
19 ISO 13438

specimen is subjected to a tensile test and measured against a control specimen taken from the same production sample. The resultant loss in tensile strength is measured.

Oxidation testing on GEOfabrics HPS 3 was undertaken at BTTG laboratories. The results can be seen in Table 5.

28 days	Control		Exposed			
	Tensile strength (N)	Ext. % @ max load	Tensile strength (N)	Ext. % @ max load	% Retained strength	% Retained extension
MD						
Mean	832.92	83.1	892.82	82.4	107.19	99.11
SD	63.45	3.42	122.50	6.68		
CV (%)	7.62	4.12	13.72	8.11		
CMD						
Mean	1063.58	94.1	1116.36	99.3	104.96	105.61
SD	60.68	11.25	61.96	3.30		
CV (%)	5.71	11.96	5.55	3.32		

56 days	Control		Exposed			
	Tensile strength (N)	Ext. % @ max load	Tensile strength (N)	Ext. % @ max load	% Retained strength	% Retained extension
MD						
Mean	832.92	83.1	1006.70	86.0	120.86	103.44
SD	63.45	3.42	65.50	5.17		
CV (%)	7.62	4.12	6.51	6.02		
CMD						
Mean	1063.58	94.1	1201.96	94.9	113.01	100.91
SD	60.68	11.25	105.50	4.60		
CV (%)	5.71	11.96	8.78	4.84		

84 days	Control		Exposed			
	Tensile strength (N)	Ext. % @ max load	Tensile strength (N)	Ext. % @ max load	% Retained strength	% Retained extension
MD						
Mean	832.92	83.1	935.12	91.8	112.27	110.51
SD	63.45	3.42	45.80	1.46		
CV (%)	7.62	4.12	4.90	1.59		
CMD						
Mean	1063.58	94.1	1124.24	100.0	105.71	106.32
SD	60.68	11.25	44.75	3.23		
CV (%)	5.71	11.96	3.98	3.23		

Table 5: EN ISO 13438 - Resistance to Oxidation - 28, 56 & 84 days

Tensile testing of HPS3 revealed no loss in tensile strength after 84 days of oven accelerated oxidation testing (or 150 years in non-reinforcing applications).

Resistance to microbiological attack by soil burial

The purpose of this test is to assess the resistance of geotextile products to attack by micro-organisms, bacteria and fungi by a soil burial test. Experience and exhumations of geotextiles manufactured from synthetic polymeric materials, in some cases for more than two decades show that most are generally resistant to this type of decay. However, it was deemed prudent to perform this test in order eliminate any doubt. Samples of GEO*fabrics* products were tested to EN 12225. The 1% loss in tensile strength recorded is of little significance and can be attributed to experimental error/ variation in sampling (Figure 6).

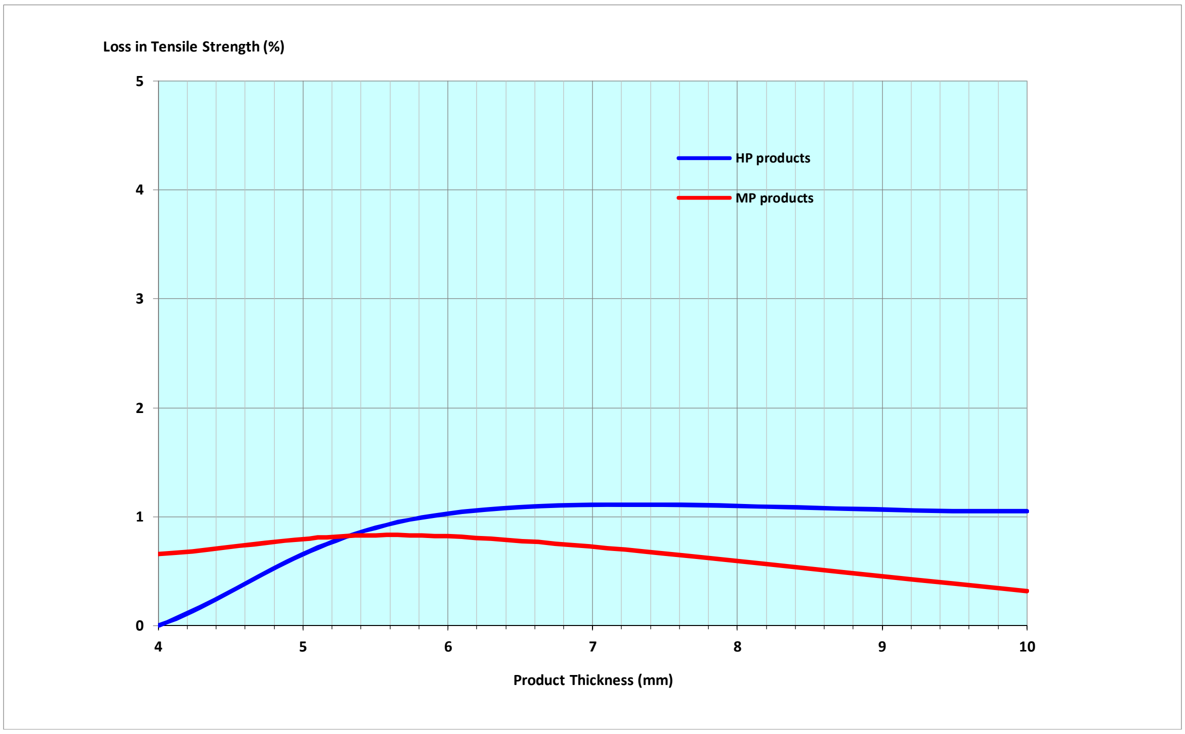


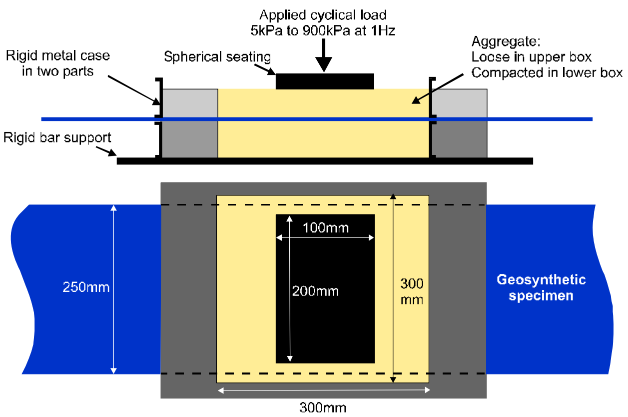
Figure 6: Microbiological Resistance: EN 12225

Procedure for simulating damage during installation

Damage during installation in this instance relates to mechanical damage normally as a result of direct contact between the soil fill and the geosynthetic under load, the effect of accidental damage caused by site plant are not accounted for. Damage can range from relatively light damage such as scuffing and abrasion of the fibres from the surface to more severe damage such as holes. The severity of the damage increases with the coarseness and angularity of the fill and applied compaction, and decreases with the thickness of the geotextile, such damage can affect the mechanical and hydraulic properties of a geotextile.

In 2002 GEOfabrics performed installation damage testing to ENV ISO 10722. The principle of the test is that a Geotextile specimen is placed between two layers of synthetic aggregate and subjected to a period of dynamic loading using a sinusoidal pressure between 5kPa and 900kPa at a frequency of 1Hz. The synthetic aggregate used is a sintered aluminium oxide with a grading of 5-10mm.

Once this is complete the sample is removed from the apparatus, examined for any visual damage and then subjected to a mechanical or hydraulic test. The results of the test are expressed as the change as a percentage of the properties measured. The layout of the test is shown in Figure 7.



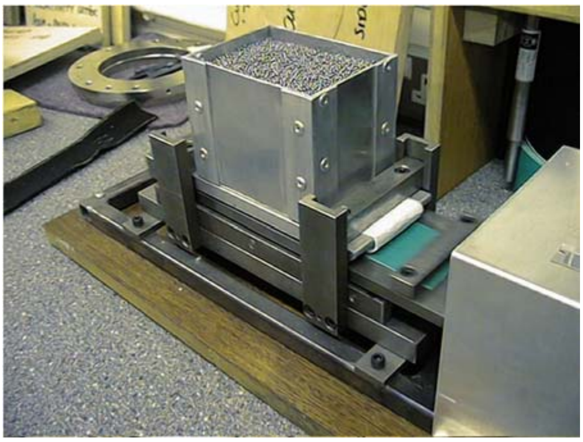


Figure 7: ENV ISO 10722 - Procedure for simulating damage during installation

The resultant loss in tensile strength after the test has been completed is shown in Figure 8. It can be seen that there is an improvement in performance as thickness increases.

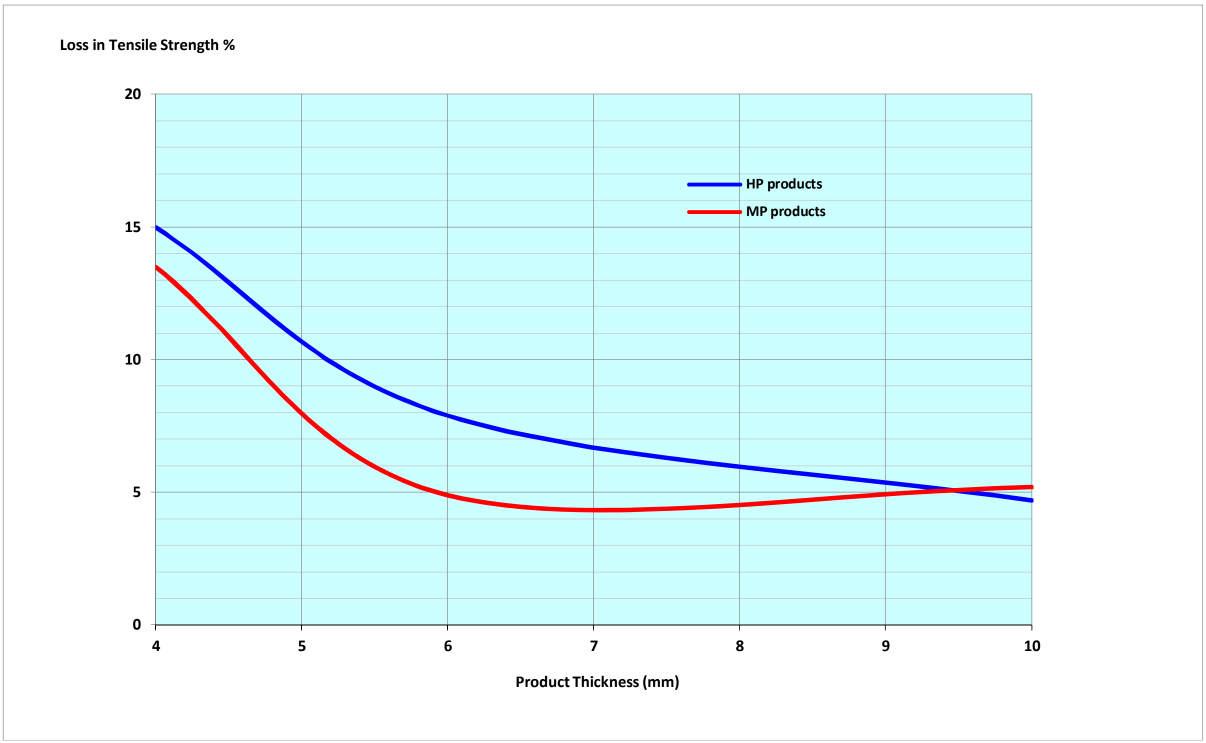


Figure 8: ENV ISO 10722 - Resultant loss in tensile strength after completion of test

Testing using site-specific leachate

In 1997 GEOfabrics set out a program to investigate and compare the performance of geotextiles manufactured from both polypropylene (PP) and polyethylene (PE) in a chemically aggressive leachate environment. The investigation was founded as a result of a claim that PE was more chemically resistant than PP, this claim was based on tests which immersed base polymers in its pure material state in pure acids or alkalis.

In order to test this theory in aggressive site leachate, a decision was made to perform a laboratory-controlled test using leachate collected from site. The initial test was performed on a leachate collected from the Orgreave contaminated land containment cell.

The principle of the test was that five samples of geotextile were taken from both GEOfabrics Protector GP90 polypropylene and GEOfabrics Protector GP151 polyethylene fabrics. The samples were then fastened using polythene yarn to glass rods and hung in on racks inside the tank. The temperature chosen was a compromise between a number of factors, similar tests are commonly carried out at 55˚C as accelerated tests (e.g. 90 days in the American EPA 90/90 tests). For this test it was decided that longer periods were preferable to simulate site conditions as much as possible.

The site temperature was around 20˚C, although the possibility that some exothermic reactions could take place in isolated pockets was recognised. In order to achieve a long-term anaerobic test it was deemed necessary to minimise evaporation and exposing the samples to air a lower temperature was desirable. Also at a higher temperature it was felt that there was a danger that biological growth would be halted or even killed off. Therefore in order to accelerate the test as much as possible without any negative results a test temperature of 35˚C was deemed to be most appropriate.

Figure 9 shows the layout of the test. The samples in this first test were immersed for 437 days, samples were removed at appropriate intervals and CBR tests were performed and compared against a control sample. The resultant change in strength is shown in Figure 10.

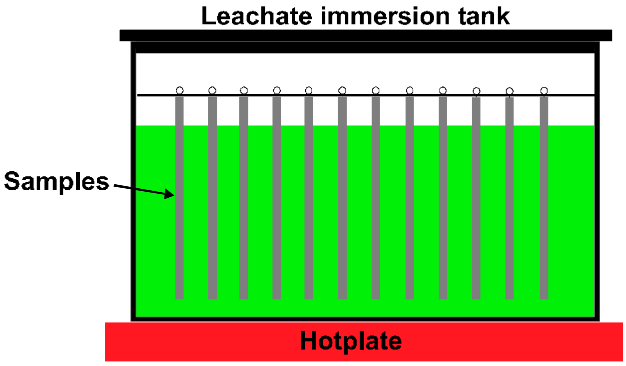


Figure 9: Long-term leachate immersion test (layout & photograph)

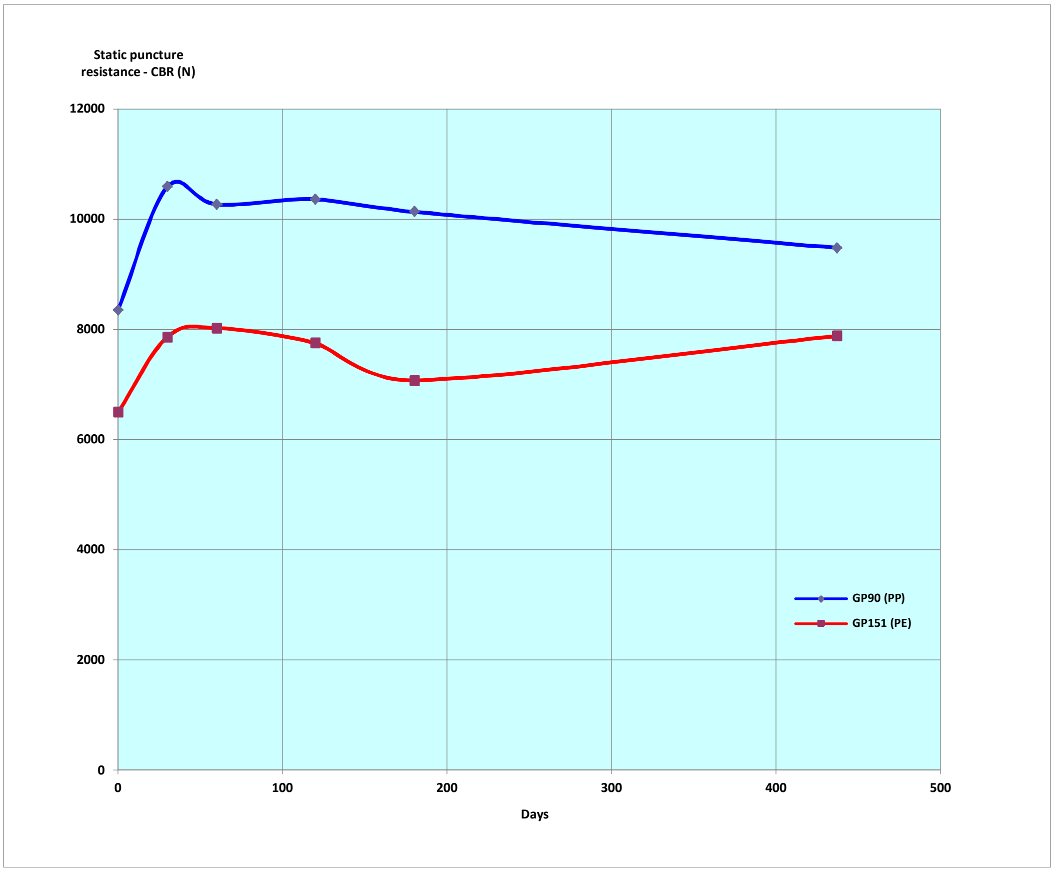


Figure 10: Aggressive leachate immersion test (Orgreave contaminated land containment cell pH 3.1)

The results of the Orgreave's test show that the there was a marked increase in puncture strength on both the PP and the PE geotextiles, with elongations generally decreasing on both of the materials. The increase in strength was seen as a combination of the stiffening of the fibres due to the increased temperature and free floating particles lodging themselves within the matrix of the fibres reinforcing the material. The test needed to be stopped after 437 days as the acidic leachate corroded the stainless steel tank at the welded seams causing the leachate to leak out.

The results showed that the PP and PE fibres behaved in a very similar way, and there was no indication that either polymer had superior performance. However, with Polypropylene being the stronger and cheaper choice, it was felt to be the appropriate way forward.

Tests have also been carried out using an evolving leachate supplied periodically from Breighton Landfill Site over the decade. During the test the level of leachate has been maintained by recharging it with samples supplied from the site providing a continuously evolving leachate to create as authentic a test as possible. This test has now been running for over a decade and is the longest running leachate immersion test in the world. The results so far are shown in fig 9.

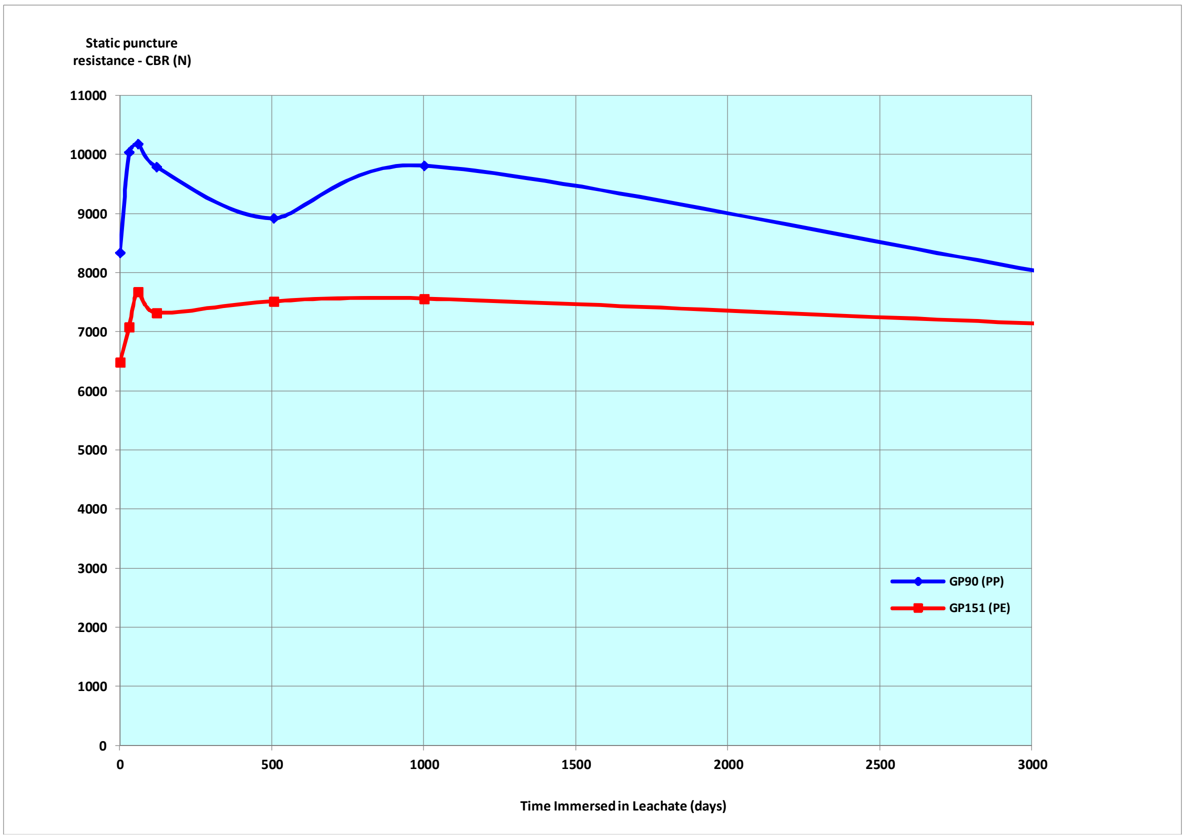


Figure 11: Long-term leachate immersion test - Breighton landfill site (pH 9-10)

Conclusions

The majority of applications that call for the use of geosynthetics require the products to perform for a minimum expected time, commonly referred to as the design life. The rate degradation of geosynthetics used must be such that the required properties time to failure exceeds the requirements of the design. The available properties must exceed the required properties for the duration of the design.

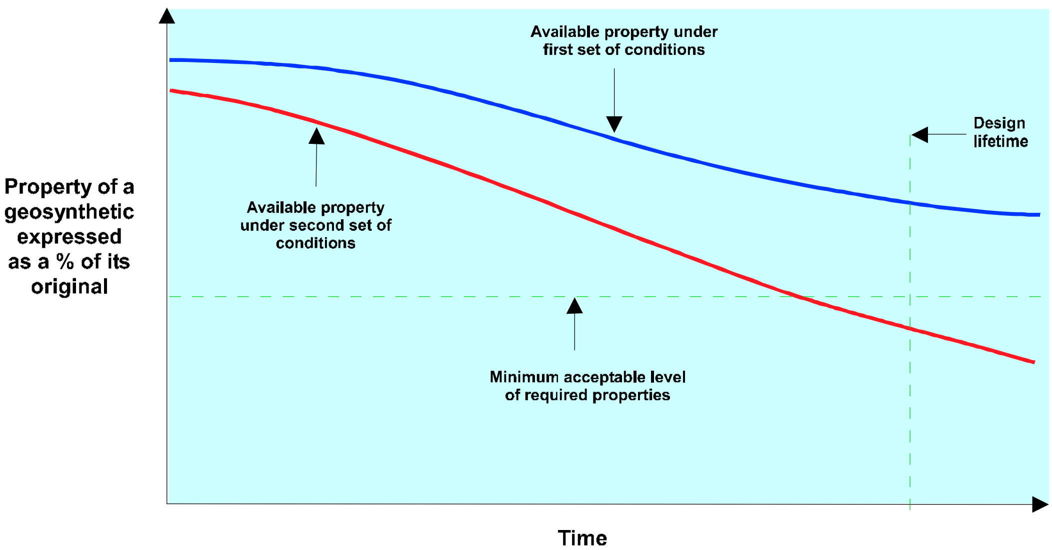


Figure 12: Available and required properties as a function of time under two different sets of conditions.[20]

20 Ref: ISO/TS 13434:2008 4.2.1

From the guidelines published by CEN and the established research on Geosynthetic durability it is possible to design a geotextile to fulfil its function for the duration of the design life. However it is imperative that the product selected uses an appropriate polymer formulation, is manufactured from fibres produced to a controlled specification and with fabric properties designed for long term use.

When selecting a geotextile a designer must take into account not only the mechanical and hydraulic properties of the geotextile at the point of manufacture, but the proven longevity of the properties in the site environment, both prior to installation and for the duration of the design. The consistency of the material provided is imperative if the tests performed in a laboratory are to be trusted.

The use of geotextiles manufactured from the bi-products of other manufacturing processes must be undertaken with extreme caution as the long term performance can never be fully known.

GEOfabrics HPS range has been engineered for long term durability, both index and performance testing has proven time and time again that the product is suitable for the most demanding civil engineering applications. Model specifications are available for specific applications, which include parameter for durability; these are available on request and can be downloaded from the GEOfabrics' web site - *www.geofabrics.com*.

Appendix

Test Report – Orgreave Site Leachate Cocktail

General analysis

Sample I.D. W/EX/94. Reference Sample Data	**6344 Sample 1**
pH Units	3.1
Suspended Solids	85
Total Alkalinity as $CaCO_3$	Nil
Chloride as Cl	275
Total Sulphur as SO_2	42600
Nickel as Ni	4.19
Chromium as Cr	5.17
Cadmium as Cd	< 0.01
Copper as Cu	0.62
Lead as Pb	1.78
Zinc as Zn	10
Arsenic as As	<0.04
Mercury as Hg	<0.05
Total Nitrogen as N	153
Ammoniacal Nitrogen as N	271
Total Cyanide as CN	0.27
Thiocyanate as SCN	27
Sulphide as S	1.68
Phosphate as P	72
Chemical Oxygen demand	>1500
Biochemical oxygen demand	1030
Total organic carbon	3510
Oil	72
Phenol index as C_3H_5OH	161

(Results expressed as mg/l except where stated)

Test Report – Breighton Site Leachate Cocktail

General analysis

Sample Ref: E504240 Data	Sample after 1 month Units
Conductivity 20C (uS/cm)	12060
pH Units	10.0
Nitrate	0.50
Nitrite	0.10
Nitrogen Ammoniacal	482
Nitrogen Total Oxidised	0.6
BOD Total +ATU	250
COD Total	2620
Chloride	2660

(Results expressed as mg/l except where stated)

Technical Data – GEOfabrics GP90 & GP151

Property	GP90	GP151
Polymer	Polypropylene (PP)	High Density Polyethylene (HDPE)
Unit weight: (gsm)	1200	1200
Thickness under 2kPa (mm)	7.0	6.5
Tensile strength MD (kN/m)	32	24
Tensile strength CMD (kN/m)	90	50
Tensile elongation MD (%)	210	165
Tensile elongation CMD (%)	120	100
CBR (N)	8500	5500
CBR displacement (mm)	80	70