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Geotextiles and geotextile-related products — Guidelines on durability

Géotextiles et produits apparentés — Lignes directrices concernant la durabilité

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Foreword

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Throughout the text of this document, read "...this European prestandard..." to mean "...this Technical Report...".

Annex A of this Technical Report is for information only.

Annex ZZ provides a list of corresponding International and European Standards for which equivalents are not given in the text.

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Foreword

This draft CEN Technical Report has been prepared by CEN/TC 189 "Geotextiles and geotextile-related products" the secretariat of which is held by IBN. It is now submitted to the CEN/BT for approval.

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1 Scope

This guide is intended to introduce the reader to the basic concepts of geotextiles durability and its assessment. Consideration of the design parameters, the project conditions and the geotextile properties leads to the definition of the appropriate tests to be performed for assessing the durability of the geotextile .

Geotextiles and geotextile-related products (referred to below as geotextiles) are available in a wide range of compositions appropriate to different applications and environments. The synthetic polymers used consist mainly of polyamide, polyester, polyethylene and polypropylene. These materials, when correctly processed and stabilised, are resistant to chemical and microbiological attack encountered in normal soil environments and for normal design lives. For such applications only a minimum number of screening or "index" tests are necessary.

For applications in more severe environments such as soil treated with lime or cement, landfills or industrial waste, or for applications with particularly long design lives, special tests including "performance" tests with site-specific parameters may be required.

This guide does not cover products designed to survive for a limited time, such as erosion control fabric based on natural fibres, nor does it cover geomembranes, nor geotextiles for asphalt reinforcement. Creep and creep-rupture, which should be taken into consideration for soil reinforcement applications, are described in outline but the use of the data in reinforced soil design will be the subject of a separate document.

2 Normative references

ENV 1897	Geotextiles and geotextile related products - Determination of the compressive creep properties
ENV 12224	Geotextiles and geotextile related products - Determination of the resistance to weathering
ENV 12225	Geotextiles and geotextile related products - Method for determining the microbiological resistance by a soil burial test
ENV 12226	Geotextiles and geotextile related products - General tests for evaluation following durability testing

ENV 12447	Geotextiles and geotextile related products - Screening test method for determining the resistance to hydrolysis
EN ISO 13431	Geotextiles and geotextile related products - Determination of tensile creep and creep rupture behaviour
EN ISO 13437	Geotextiles and geotextile related products - Method for installing and extracting samples in soil, and testing specimens in the laboratory
prENV ISO 13438	Geotextiles and geotextile related products - Screening test method for determining the resistance to oxidation
ENV ISO 12960	Geotextiles and geotextile related products - Screening test method for determining the resistance to liquids
ISO 10318	Geotextiles - Vocabulary

3 Definitions

3.1 Durability

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. Any application may require one or more functions from the geotextile. The five functions defined in ISO 10318 are drainage, filtration, protection, reinforcement and separation. Each function uses one or more properties of the geotextile, such as tensile strength or water permeability. These are referred to as functional properties.

Assessment of the durability of structures using geotextiles requires a study of the effects of time on the functional properties. The physical structure of the geotextile, the nature of the polymer used, the manufacturing process, the physical and chemical environment, the conditions of storage and installation, and the different loads supported by the geotextile are all parameters which govern the durability. The main task is to understand and assess the evolution of the functional properties for the entire design life. This problem is quite complex due to the combination and interaction of numerous parameters present in the soil environment, and to the lack of well documented experience.

This guide is only intended to cover the durability of the materials; the durability of the geotechnical structure as a whole should be treated separately.

The object of the durability assessment is to provide the design engineer with the necessary information (generally defined in terms of material reduction or partial safety factors) so that the expected design life can be achieved with confidence.

3.2 Available and Required Properties

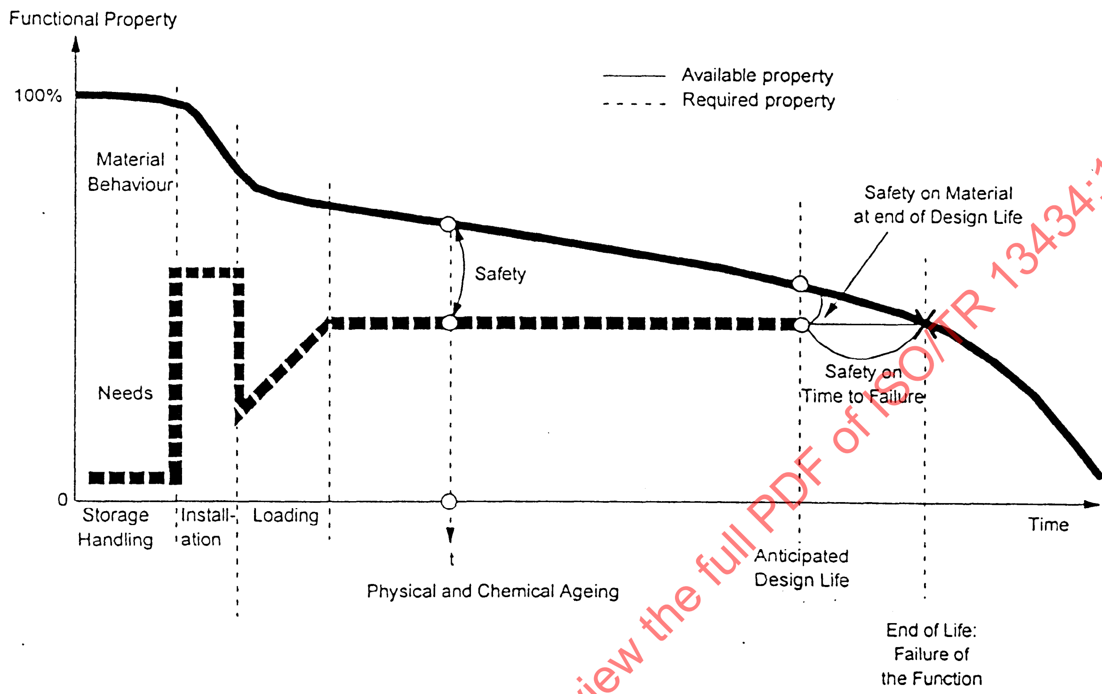

Fig. 1: Typical available and required values of a functional property as a function of time

It is first necessary to differentiate between the available and required values of a functional property. Figure 1 is a schematic reresentation of the evolution of the available property of a material as a function of time, as represented by the upper curve on the graph. The functional property may be a mechanical property such as tensile strength or a hydraulic property such as permeability. Along the time axis is indicated the events that happen between manufacture of the product and the end of product life. The lower curve represents the changes in the required property during these different and successive events. The shape illustrated applies to mechanical strength but would not be very different for a hydraulic property. One can see that after the loading phase, usually by the end of construction, the property required is considered to be constant and equal to the level defined by the design. In some applications the required level may change after a certain time, for example in the construction of a wall or increased water flow in a drain, in which cases the effect of these changes on durability should be assessed.

In the following sections the two curves are examined in more detail, using as an illustration the tensile strength of a geotextile in a reinforcement application.

3.3 Required Property

During the first period of product life, a minimum strength is needed to resist handling and transportation loads. Once on site, placing and compaction of the backfill may for a short time require a strength higher than that required for the design life. After installation and as construction progresses, the applied loads increase until they reach a peak .

The required tensile strength is estimated by means of empirical calculation methods. As recognised by most codes, there are uncertainties in the intensities and effects of the applied loads: weights, surcharges, earth pressure. To cover for these uncertainties, the calculated loads are multiplied by a first series of partial safety factors (or load factors). The calculated stresses are then multiplied by a second partial safety factor to cover the relative inadequacy of the calculation model. This calculation defines the maximum design load deemed to be constant throughout the entire design life. The design method and the definition of safety factors are not the subject of the present document. Reference should be made to the appropriate Eurocode.

3.4 Available Property

At any time, the tensile strength required by the design should be smaller than the available strength. The evolution of the available product property with time is complex, and arises from various mechanisms. These should be analysed in order to ensure sufficient available strength at any time, in particular at the end of the anticipated design life.

A new product exhibits a 'short term' or 'initial' property as defined by a set measurement standard. Depending on the level of quality control and quality assurance, a reduction factor may be applied to cover variations in the initial property. During storage and installation, this property may change due to weathering and mechanical damage.

The extent of the mechanical damage depends on the product, the nature of the materials in contact with the geotextile, the equipment used and the care provided by the operator.

Installation reduction factors should be considered for each product and typical backfill, based on systematic tests. A simple reduction factor equal to the ratio of the strengths of undamaged and damaged material is convenient but may not describe adequately the effect of damage on long-term strength. Surface scratches or cracks may not significantly alter the short-term behaviour but could lead to a reduction in long-term rupture life. This is still a subject of research. Results should be interpreted prudently.

After installation, the operating life of the structure starts. During the operating life the geotextile is subjected to chemical, biological or physical actions due to the soil, its constituents, and its air, water and organic content. The typical degradation mechanisms of the polymers used to manufacture geotextiles will be reviewed in the next section. The reduction in strength may be due to loss of mass, for example due to erosion of the surface, or to chemical modification, and should be taken into account by specifying reduction factors.

In addition to the effect of the soil and its contents, the time to failure of the geotextile can also diminish due to the level of the applied load: the greater the applied stress, the shorter the time to failure. This is a particularly important phenomenon that will be described in 5.4.1. Thus there is an interaction between the required property and the available property. There is no absolute available property curve.

Obtaining the property curve is not an easy task. Temperature plays a major role in all degradation mechanisms and in mechanical behaviour (creep and rupture). The results of short-term accelerated tests, often using high temperatures as a means of acceleration and lasting for one year or less, need to be related to long-term design life. This extrapolation assumes that the degradation mechanisms are the same at both test and service temperatures and over the entire design life of the structure.

Precautions should be taken to ensure that no transition, such as a change in the state of the polymer or of the geotextile, occurs during the design life or in applying accelerated testing, unless that transition is fully understood and taken into account in the extrapolation.

Failure implies that the geotextile can no longer perform the function for which it is being applied. For example, if the function is filtration, a greater reduction in mechanical strength may be acceptable than if the function is reinforcement.

Partial safety factors are required to describe the various degradation mechanisms (eg light intensity, chemical concentration). These factors are listed in 7.9.

The testing techniques and the assessment methods for estimating the property curve will be presented and discussed in later sections. As described in 7.1, index test methods are intended to ensure a minimum level of durability and do not constitute a comprehensive assessment procedure. Where this is needed it will be necessary to carry out further performance tests more closely related to service conditions. These tests may also include investigations on samples extracted from sites where the same product has been used for several years in a similar environment. The procedure is described in prEN ISO 13437. As in other fields of engineering, confidence in the durability of geotextiles can only be expected to develop gradually as the technology matures and the results of long-term service experience accumulate. Examples of experience to date are described in clause 6.

3.5 Design Life

The design life is specified on the time axis. It is set by the client and is decided at the design stage. The codes generally propose several fixed durations 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 and the consequences of failure may influence this duration (example: 70 years for a wall, 100 years for an abutment). Many geotextiles have a temporary function although the structure 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 (generally also indicated by codes), such that failure is predicted to be well beyond the design life. The ratio of the predicted available property to the predicted required property represents the total safety factor for that component. This can also be expressed in terms of the time to reach failure if the geotextile were to be left in service after the end of design life. These two representations of safety, the ratio of required and available property at the design life, and the ratio of the predicted end of life to design life, should be considered together because in combination they give a better idea of the real level of safety that exists.

3.6 End of Life

End of life is the point on the time axis where the available property curve meets the required property curve. At this point the product is predicted to fail. Residual service may remain either if the expected loads are overestimated, or if they imply a combination of degradation mechanisms that may not all have reached their maximum values. Whatever the case, beyond that point on the graph the possibility of failure is high.

3.7 The durability study

The design and durability assessment of a structure using geotextile can be summarised as follows:

The design consists of:

- defining the function of the geotextile
- making the inventory of loads and constraints imposed by the application
- defining the design life of the geotextile
- quantifying the required properties of the geotextile (eg strength, permeability)
- defining the quality and quantity of the geotextile material needed

- making sure that the estimated available properties at the end of the design life are greater than the required properties; the factor of safety for the material being the following ratio:

$$\text{factor of safety} = \frac{\text{Available properties at the end of design life}}{\text{Required properties from loads and constraints}}$$

The factor of safety should be greater than unity.

The durability study consists of:

- listing significant environmental factors (see clause 5)
- defining the possible degradation phenomena with regard to the selected materials and the environment
- estimating the available property as a function of time
- supplying the designer with suitable reduction factors or available properties at the end of their design life.

Details are given in clause 7.

4 Constituents of Geotextiles

4.1 General

The durability of a geotextile depends upon the basic polymer from which it is made, on any additives compounded with it, on the polymer microstructure, 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 the geotextiles are generally thermoplastic materials which may be amorphous or semi-crystalline. An amorphous polymer has a randomly coiled structure which at the glass transition temperature T_g undergoes significant change: from a stiff, glassy, brittle response to load below the glass transition temperature to a more ductile, rubbery response above T_g. Most polymers used in geotextiles are semi-crystalline, that is they contain small well-oriented, closely packed crystallites alternating with amorphous material. Since the change in behaviour only affects the amorphous regions, the glass transition is less marked for a semicrystalline polymer. At a higher temperature, however, the crystallites melt, which produces an abrupt change in properties. In civil engineering applications polyesters are used below their T_g while polypropylene and polyethylene are used above T_g. Any acceleration of laboratory tests crossing a transition such as T_g should be regarded with caution.

Any polymer, whether amorphous or semi-crystalline, 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 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.

The orientation of polymers by mechanical drawing to form fibres and filaments results in higher tensile properties and improved durability. As the molecules become more oriented, the fibres become stronger. The crystallites are retained and the ratio of crystalline regions and amorphous regions should be properly balanced to produce the physical properties necessary for fibres used in geotextiles. The increased orientation and associated higher density leads to higher environmental resistance.

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 and yield or tensile strength, hardness and softening point, and to a decrease in chemical permeability. Neighbouring crystallites may be connected by single molecules running through the amorphous regions, which under tension become taut and make a significant contribution to the mechanical behaviour. These 'tie' molecules are, however, susceptible to chemical attack.

Durability may also be influenced by fibre thickness, and the volume to surface ratio. Some means of degradation, such as oxidation and UV-exposure, are dependent on surface area, while others such as diffusion and absorption are inversely related to thickness.

4.2 Individual Polymer Types

The polymers used in geotextiles are described below and three of their most important physical properties are listed in Table 1. The most commonly used are polypropylene and polyethylene.

Polypropylene (PP) is a thermoplastic long chain polymer. PP is 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 stabilisers are added to prevent oxidation during manufacture and generally to improve long term durability, including weathering.

Polyethylene (PE) is one of the simplest organic polymers. It is used in its low density form (LDPE), 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 stabilised to increase its resistance to weathering. Certain grades can be susceptible to environmental stress cracking.

Polyesters are a group of polymers. The type used most frequently in geotextiles is polyethylene terephthalate (PET) which is a condensation polymer of a dibasic acid and a dialcohol. Since it is used below its T_g, 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.

Polyvinylchloride (PVC) is the most significant commercial member of the family of vinyl-based resins. PVC is the most versatile of all plastics because its blending capability with plasticisers and other additives allows it to take up a great variety of forms. Plasticisers are used in quantities of up to 35% to create more flexible compounds, the choice of plasticiser being dictated by the properties desired. Conversely, PVC absorbs certain organic liquids which have a similar plasticising effect. PVC also tends to become brittle and darken when exposed to ultraviolet light or heat-induced degradation.

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.

Table 1

Typical physical properties for polymers used in geotextiles

	HDPE	PP	PET	PA	PVC
Density, (g/cm^3)	0.95	0.91	1.38	1.12	1.3 to 1.5
Melting temperature, (ºC)	130	165	260	220 to 250	
Glass transition temperature, (ºC)	-100 to -70	-20 to -12	70 to 80	40 to 60	-25 to 100

4.3 Manufacturing Processes

Geotextiles and geotextile-related products are manufactured using several different processes. In this section the main processing technologies for the manufacture of geotextiles, geogrids, geonets, geocells and geocomposites will be described.

Geotextiles include nonwoven, woven and knitted products. All are made of polymers drawn into fibres or yarns, which consist of a number of fibres. The different manufacturing processes lead to geotextile products with a wide range of properties.

For the production of nonwoven geotextiles continuous filaments or staple fibres (cut fibres) are used. Woven and knitted geotextiles are produced using different types of yarn such as spun yarns, multifilament yarns, monofilaments and film tapes or split film yarns.

The types of fibres, multifilaments, monofilaments and tapes used in the manufacture of such geotextiles are produced mainly by a melt spinning process. To produce fibres, multifilaments and monofilaments the molten polymer is extruded through orifices of a die, cooled, drawn by stretching and according to the end use:

1) laid on a screen to form a planar structure (continuous filament or spun bonded nonwoven);
2) processed to staple fibres by crimping and staple cutting or
3) processed to multi- or monofilaments and winding the filaments after drawing and annealing directly on to spools. In the case of multifilament production this technique is known as spin drawing.

Spunbonded nonwovens are continuous filament nonwovens and are manufactured in a continuous process starting with the polymer and proceeding through filament production, geotextile formation and filament bonding in the same line, finishing with the roll of nonwoven.

Staple fibre nonwovens are manufactured in a two stage process: the first stage consists of fibre production (extrusion and cutting) and the second stage consists of the formation of the geotextile, bonding and production of the finished roll.

Woven geotextiles are also produced in a discontinuous process with at least two stages. The first stage is the production of the yarn, monofilament or multifilament. The second stage is the weaving either to flat wovens (or simply wovens) or knitted wovens (knits).

Film tapes and split yarns are normally only produced from polypropylene and polyethylene. These products are made by extruding a film, cutting the film into individual tapes and stretching them by a uniaxial drawing process. Coarse film tapes are too stiff for further handling in beaming and weaving, and are therefore fibrillated after the drawing process and before winding and twisting. These types of yarn are then called split film yarns.

The drawing process is very important in the production of the different types of polymeric fibres, filaments and tapes. During this process the polymeric chains become aligned along the filament or tape length and their crystallinity, mechanical properties and durability all increase. The mechanical properties of the product depend upon the details of the manufacturing process.

Bonding of nonwoven geotextiles formed from either continuous filaments or from staple fibres is done mechanically by needle punching with felting needles, by thermal (cohesive) bonding using heat with or without pressure (calendering), by chemical (adhesive) bonding, or by a combination of these processes.

The physical structure and properties of the nonwoven products are linked to the bonding system. For example heat bonded wovens and nonwovens (tape film wovens) are thin products in which the fibres are oriented in a two-dimensional structure. Needle punched nonwovens have a three-dimensional structure, the configuration of which may be fixed by a final thermal bonding stage.

The structure of the fabric will contribute to the durability properties, for example thick fibres and tapes are less susceptible to weathering. The stabilisation systems applied to improve the properties are therefore adjusted to suit either a nonwoven geotextile of finer fibres, a woven geotextile or a geogrid.

Extruded geogrids are manufactured from a polyolefin sheet containing holes that have been punched or preformed during extrusion. The perforated sheet is then stretched either uniaxially or biaxially under controlled conditions of load and temperature to achieve a high level of molecular orientation.

Geonets are manufactured typically by an extrusion process in which a minimum of two sets of strands (filaments) are overlaid to yield a three-dimensional product. The openings between the strands permit in-plane flow of water or landfill leachate.

Geocomposites are composed of at least two different geotextiles or geotextile related products joined together by a process such as bonding, gluing, welding, weaving or sewing.

Geocells are three-dimensional geosynthetics used for soil confinement in erosion control applications. They are manufactured either by extrusion, HDPE strip welding or geotextile strip welding.

A detailed description of current geotextile and geotextile related products, and of their manufacturing processes, is given in Annex A, ref. 1.

Based on many years' experience of manufacturing and the development of quality assurance procedures, geotextile products are made in such a way that good physical durability properties are obtained.

4.4 Recycled Materials

It is common practice within the plastics industry to recycle the processed material (in-house scrap polymer), since it can be considered as comparable to virgin material as long as it is used in small percentages (less than 10%). Some producers manufacture their geotextiles using 100% post-consumer recycled polymer, for example reground PET bottles.

Recycled materials may originate from various stages of processing following their original formulation, or from subsequent processes such as weaving. The materials may have been used in service, whether in the form of textiles or as other products such as packaging. 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.

4.5 Additives and Stabilisers

Additives play a major role in polymer stabilisation. Typical additives used in the production of geotextiles are antioxidants and UV stabilisers.

Antioxidants prevent deterioration of the appearance and of the physical properties of polymers caused by the oxidative degradation of polymer bonds. Oxidation is accelerated by the heat generated during the manufacturing process. Thus some antioxidants are designed to work during the manufacturing process (high temperatures), while others are intended to protect the geosynthetic during its subsequent exposure to the environment (low temperatures). Stabilisation is achieved by either providing alternative opportunities for termination reactions, or by preventing the formation of free radicals and thus interrupting the chain of reaction. With some stabilisers oxidation occurs over a short interval after a long incubation time, while with others the reduction in properties is a gradual process. This can make the interpretation of accelerated oxidation tests difficult.

UV stabilisers provide ultraviolet light stabilisation of polyolefins and other polymers by several mechanisms such as reducing the rate of photo-oxidation, absorbing the light of the critical wave length or by reduction in the kinetic chain length of the propagation stage of the photo-oxidation mechanism. The kinetic chain length can be reduced by free radical trapping.

Typical light stabilisers are carbon black, hindered amine light stabilisers (HALS) and UV light absorbers.

5 Environmental factors that may lead to degradation

5.1 The environment above ground

Ageing of geotextiles above ground 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 and deposits from polluted air.

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. This is a general property of polymers and is not restricted to geotextiles. Additives increase resistance to ultraviolet radiation in a variety of ways as described in 4.6.

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. Since natural weathering is both seasonal and variable, artificial tests have the advantage not only of being able to increase the intensity of the radiation, but also ensure that the radiation is constant, controlled and up to 24 hours a day. The performance following accelerated testing is related to the duration of exposure on site as described in 7.2.

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. The need for either short or long term resistance to weathering therefore depends on the application.

Exposure to UV has been shown to reduce the subsequent chemical resistance of thin textiles but this has not been observed in geotextiles. In addition, atmospheric pollution and acid rain may enhance UV degradation, particularly of PA, for longer exposures above ground. Attack by birds has been observed during deliberate exposure of specimens during outdoor weathering tests.

5.2 The environment below ground

5.2.1 Soils

Below ground the main factors affecting the durability of geosynthetics are as follows:

particle size distribution and angularity
acidity/alkalinity (pH) - humates, sodium or lime soils, lime hydration, concrete

metal ions present
presence of oxygen
moisture content
organic content
temperature

Adequate specification of the soil is thus essential for proper consideration of the durability of the geotextile.

Soils as encountered in Western and Central Europe should be divided into topsoils (0.20 - 1.00m) and underlying sediments. Their nature depends primarily on the underlying rock and on the local climate, including the mean temperature and the drainage conditions. Topsoil is a mix of weathered sediments and humus produced by decaying organic material. The conditions of decay can be aerobic, with oxygen present, or anaerobic.

Sediments are deposits of minerals and mostly lack organic material. They are generally formed by the physical and chemical weathering of rocks. Silt, sand and gravel (particle size 0.002 to 60 mm) are formed by physical weathering, while clays (particle size < 0.002 mm) are formed by chemical weathering. Fills and backfills originate from sediments, where particle size and angularity is determined not only by the manner in which the sediment was formed but also by any subsequent industrial processing such as crushing. Sediments can cause considerable mechanical damage to geotextiles, in fact the exhumation of specimens after a number of years often shows that this is the only form of degradation that can be identified with certainty. The range of particle sizes of a soil is measured by sieving and is depicted by a graph of particle size against percentage by weight. Mechanical damage increases with particle size, and with the angularity of the particles. This is described further in 5.3.3.

The topsoil or sediments can be fully saturated, partially saturated or dry, or intermittently wet and dry. In wetter climates the drainage is principally downwards, drawing soluble materials to lower levels, while in drier climates moisture is removed by evaporation at the surface and the resultant upward movement of the water draws these soluble fractions upwards and deposits them at the surface. The water content of an unsaturated soil is described by the local relative humidity.

The temperature of the soil is constant (to within ± 0.5ºC) only at a depth of 10 m or more. Its value is then equal to the annual average atmospheric temperature at the surface. Daily and seasonal variations occur with decreasing intensity as the distance from the surface increases. For example, the daily variation in atmospheric temperature and solar radiation is felt to a depth of half a metre (Annex A, ref. 2). Since higher temperatures increase the rates of ageing and creep of polymers disproportionally, their effect on geotextile behaviour may need to be considered for material installed close to the surface.

Chemical attack is most serious when the polymer chain backbone is broken, leading to a loss of mechanical properties. This will generally occur by means of oxidation or hydrolysis, depending on the type of polymer and on the acidity or alkalinity of the soil. Acidity and alkalinity are expressed as pH, a scale with neutral soil having a pH of 7, lower values implying acid soils and higher values alkaline soils.

In Europe topsoil generally has a pH of 5.5 - 7, 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, as shown in Table 2, with values between 2 and 10 having been recorded.

Table 2: Some typical minerals and fills and their pH values

Minerals and fills	Formula	Maximum pH
Felspar		
Albite	$NaAlSi_3O_8$	9 - 10
Anorthite	$CaAl_2Si_2O_8$	8
Orthoclase	$KAlSi_3O_8$	8 - 9
Sand		
Quartz	SiO_2	7
Muscovite	$KAl_2(OH,F)_2AlSi_3O_{10}$	7 - 8
Clay		
Kaolinite	$Al_4(OH)_8Si_4O_{10}$	5 - 7
Carbonate		
Dolomite	$CaMg(CO_3)_2$	9 - 10
Calcite	$CaCO_3$	8 - 9

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 with pH values of 8.5 to 10. Some geocomposites contain bentonite in dry form which combines with local ground water to form a gel.

5.2.2 Chemical effects on the geotextile

Polyester and polyamide fibres are susceptible to hydrolysis, which in polyester fibres 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 or etching. 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. It takes place throughout the cross-section of the fibre. The rate of hydrolysis is very slow, such that the process has little effect at mean soil temperatures of 15 ºC or below in neutral soils, although it can be accelerated in acids. The rate of internal hydrolysis in a partially saturated soil depends upon the local relative humidity.

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. On the other hand, the tendency to oxidation decreases due to the reduced availability of oxygen in soil.

All chemical reactions occur more rapidly at higher temperatures, as described by Arrhenius' Law (see 7.3.5).

In the past 20 years there have been no reports of microbial attack on synthetic geotextiles either in testing or in the ground. Only geotextiles containing vegetable fibres, most of which are deliberately designed to degrade once natural vegetation has become established, are likely to be affected. However, in topsoil micro-organisms such as bacteria and fungi might attack geotextiles if they contain components that provide nutrition and if the micro-organisms can penetrate the remaining polymer. 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 biostabilisers. Micro-organisms could in theory produce degradation products that attack geotextiles chemically. The soil burial test (ENV 12225) endeavours to provide a soil of maximum biological activity to encourage any reaction that can occur.

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. To simulate attack by rodents or penetration by roots no specific index tests are proposed.

5.3 Effects of Load and Mechanical Damage

5.3.1 Tensile Load: Creep and Stress-rupture

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 recognised early in the development of geotextiles and led to an increasing number of testing programmes to provide the information necessary for the design of reinforced soil structures.

At higher loads creep leads ultimately to stress-rupture, also known as creep-rupture or static fatigue. The higher the applied load, the shorter the lifetime. Thus as mentioned in clause 3 the design load will itself limit the lifetime of the product.

Creep and stress-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.

At the microscopic level, when a load is applied to the polymer it may cause the long chain molecules to stretch or rearrange themselves. A particularly important part is played by the "tie" molecules, which run from one crystallite to another, linking them together. In polyester molecules the load can cause neighbouring links to change their orientation relative to one another, resulting in the characteristic S-shaped stress-strain curve. These processes of rearrangement continue under the combined effects of load and thermal activation, and it is noticeable that in polymers 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 used below T_g . Thus creep is more pronounced in polyethylene and polypropylene than it is in polyester.

Tensile creep is measured using EN ISO 13431, in which a specimen generally 200 mm wide is placed under a constant load for a set time, typically 1000 hours (six weeks) or 10000 hours (1,14 years), and the elongation monitored. Such tests can be performed over a range of loads and if required at various temperatures. In a reinforced soil structure part of the load will in fact be transferred to the soil so that the creep measured in air represents a maximum or conservative value. The use of creep data in the design of reinforced soil will be the subject of a separate document.

5.3.2 Synergy of tensile load with environmental effects (environmental stress cracking)

Environmental effects generally have little effect on creep strain but can reduce the stress-rupture lifetime. If the combined effect of load and environmental effect is greater than the addition of their individual effects then there is said to be synergy between them.

Environmental stress cracking, ESC, is the embrittlement of polymers caused by the combination of mechanical stress and a chemical fluid. It is more critical in amorphous polymers such as PVC, where very small fractions of a chemical, often a subsidiary additive to a compound liquid, have been known to cause critical failures.

Semi-crystalline polymers such as polyethylene are less susceptible, but not immune, to environmental stress cracking. The stress-rupture of polyethylene geomembranes has been studied very widely and is known to be accelerated by certain fluids, some of which are used deliberately in order to accelerate crack growth in testing. On the other hand, modern grades of polyethylene are very resistant to stress-rupture in air and to environmental stress cracking. This has been achieved by modifications to the polymer such as by increasing the high molecular weight fraction and by copolymerisation.

Susceptibility to stress cracking can be measured by immersing notched samples under load in a bath of liquid and can be accelerated by raising the load, liquid concentration or temperature. It is then necessary to carry out longer term tests to establish the degree of acceleration.

Drawn polyester or polypropylene fibres, or the ribs of drawn geogrids, are comparatively resistant to ESC (Annex A, ref.3).

5.3.3 Loading during installation: Mechanical Damage

Mechanical damage is caused by direct contact between the soil fill and the geosynthetic under pressure. Light damage consists of scuffing and abrasion of the fibres on the surface, while more severe damage may include cuts and holes in the fabric. Sheaths or coatings may be cut away to reveal the fibres they protect. The surface of geogrids and membranes may be abraded, and oriented polymers may split along the direction of orientation. The susceptibility of some geosynthetics to mechanical damage during installation can increase under frost conditions. The severity of the damage increases with the coarseness and angularity of the fill and with the applied compactive effort, and decreases with the thickness of the geosynthetic. Clays, sills and sands (d_{50} < 2 mm) generally produce little mechanical damage. This damage may reduce the mechanical strength of the geosynthetic and when holes are present it will affect the hydraulic properties as well.

The occurrence and consequences of mechanical damage can be assessed by carrying out a site test to prEN ISO 13437, or by simulating the effects a trial (Annex A, ref.4). The partial safety factor for mechanical strength is expressed as a ratio of the strengths of the undamaged to the damaged material (i.e. >1).

5.3.4 Normal pressure: Compressive Creep

Soil pressure can cause compressive creep in drainage materials where two outer fabrics are separated by an openwork structure to allow flow in the plane of the geotextile. Compressive creep can lead to a reduction in the distance of separation, restricting the flow, or ultimately to collapse of the openwork structure. Compressive creep should be determined by the method of ENV 1897.

5.3.5 Abrasion and Dynamic Loading

Geosynthetics used under roads, railways or in coastal erosion protection may be subject to dynamic loading which will lead to mechanical damage to the geosynthetic in a manner similar to mechanical damage on installation. While fibres and bulk thermoplastics are susceptible to mechanical fatigue, the principal cause of degradation is abrasion and frictional rubbing. The test for mechanical abrasion is prEN ISO 13427 but there is no test for mechanical fatigue.

Geosynthetics intended to operate under severe dynamic loading should therefore be subjected to performance tests which simulate or accentuate the site conditions.

6 Evidence of the durability of geotextiles

6.1 Historical development

Large quantities of geotextiles made from man-made fibres were used in the Netherlands after the catastrophic flooding of 1953, inundating 150000 hectares and killing 2000 people. To stop the flooding and reconstruct the sea barriers many million square metres of woven synthetic fabric were used, partly because at that time Europe had run out of jute for sandbags and willow fascines for seabed protection.

In the 1960's a range of nonwoven fabrics was manufactured for use as foundation, separation and filter layers between granular fills and weak subsoils. In the 1970's different grades of reinforcing materials such as heavy wovens and extruded geogrids were developed specially for such applications. While the incentive to develop geotextiles may have originated from a shortage of natural fibres, now geotextiles are produced worldwide because of their cost-effectiveness.

6.2 Empirical evidence of durability from geotextiles extracted from the soil

Will geotextiles last for 50 years, 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. These observations can then be compared with the results of accelerated and other laboratory tests.

During the period 1965-1980 Sotton et al reported on nonwoven samples of polyester and polypropylene retrieved from 25 sites in France, ten to fifteen years after installation (Annex A, ref. 5). 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. The reduction in strength was due mainly to mechanical damage occurring principally during installation.

In the following decade 1980-1990 Leflaive reported on a five metre high vertical wall in Poitiers, France, which had been constructed in 1970 (Annex A, ref. 6). In this case five metre long polyester 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 30°C 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 polypropylene, part of a quantity of four million square metres that had been laid as the backing of block mattresses on the sea bed of the Oosterschelde in 1978 to prevent scouring (Annex A, ref 7). The fabric had been in sea water at 10ºC for nine years with a local partial pressure of 3% oxygen. The permanent load was only 10% of the tensile strength. The design life was expected to be determined by the time to embrittlement of the polypropylene due to oxidation. After visual examination and analysis to determine the remaining antioxidant content, the samples were subjected to accelerated oven ageing and compared with unexposed samples from the original source of material. Subsequently, 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 polyester fabric retrieved from a soil retaining structure (Annex A, ref 8). A multi-layered geotextile reinforced wall, 4 m high, with slopes of 2:1 and 4:1, was constructed in the Netherlands to study possible degradation of the woven polyester fabric with time. Thirteen years later the wall was carefully dismantled and the mechanical and chemical properties of the yarns investigated. The 50 m long embankment was oriented from east to west to provide slopes facing north and south. These slopes were 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 (23) had not changed. On the unprotected north and south slopes a reduction of between 15% and 50% in tensile strength was observed, which was concluded to be due mainly to ultraviolet radiation and not to hydrolysis.

7 Durability Study

7.1 Need for testing

Geosynthetics cover a wide range of products, applications and environments. The main questions raised are when and why it is necessary to carry out durability testing. The following are intended as guidelines based on current knowledge and experience. They apply to polyethylene, polypropylene, polyester (polyethylene terephthalate) and polyamide 6 and 6,6 only: a separate durability assessment should be made of geosynthetics based on other polymers.

Weathering tests should be carried out on all products to ENV 12224 and evaluated in accordance with 7.2.

Mechanical damage tests should be carried out as performance tests related to the actual soil and equipment used in accordance with accepted practice (Annex A, ref 4), or as laboratory tests once a European Standard has been developed.

Creep testing should be carried out to prEN ISO 13431 for all applications in soil reinforcement. For permanent structures in reinforcement applications the minimum test period should be 10,000 hours.

For applications where the geotextile has a design life of less than five years in natural soils and the consequences of failure are low, no further testing is necessary. In some such applications the soil structure itself may have a longer design life, but the geotextile no longer plays an essential part.

For applications with design lives up to 25 years, being the current limit of experience with geosynthetics, screening tests are necessary on all products. This is particularly the case for those that contain recycled materials. These "index" tests, ENV 12225, ENV 12226, prENV ISO 13438, ENV ISO 12960 and ENV 12447, are designed around a minimum design life of 25 years in normal conditions and are designed to exclude materials where there is any doubt concerning their durability. Most durability tests intensify the parameters, for example by increasing the temperature, the applied load or the intensity of radiation, in order to accelerate degradation and allow the test to be completed within an acceptable time. Screening tests are not intended to be regular quality control tests, nor do they provide sufficient information for the prediction of time to failure, since the degree of acceleration varies from one polymer type to another. In addition, manufacturers using recycled materials are expected to maintain sufficient control over the uniformity of their feedstock such that the index tests remain valid.

Products where 25 years' satisfactory design life under comparable site conditions can be demonstrated, including new products using the same yarns and polymers, may be exempted from the screening tests. Assessment of the evidence of durability is a matter for the approvals authority responsible for the individual works.

For the following conditions further testing should be considered:

- all applications with design lifetimes exceeding 25 years;

- applications of polyester in highly alkaline environments with pH >10.0, particularly in the presence of lime, cement or concrete, or for long design lives with pH >9;

- applications of polyamide in aerobic acid environments, landfill sites or contaminated ground;

- applications in which the geotextile is likely to be exposed to temperatures greater than 25°C or less than 0°C for a significant period.

Test methods for such environments are likely to be "performance" tests which define the general method for testing and evaluation but leave certain parameters to be defined, such as the choice of backfill in a mechanical damage test or the chemical to be used in testing the resistance of a protection geotextile to a landfill leachate.

Accelerated tests such as that for resistance to oxidation may require exposure of specimens at various temperatures in order to predict longer lifetimes at lower temperatures from the trend of shorter lifetimes at higher temperatures. The results of tests with site-specific parameters may not be used in classification systems.

7.2 Resistance to weathering

During storage and on the construction site the stability of the geotextiles against weathering before installation is important for the performance of the used geotextile. The ageing of geotextiles is mainly initiated by the climatic influences through the action of solar radiation, heat, moisture and wetting. The principle of the test is to expose the specimens to simulated solar ultraviolet radiation for different radiant exposures with cycles of temperature and moisture.

Unless they are to be covered on the day of installation, all materials should be subjected to an accelerated weathering test to ENV 12224. The strength retained by a geotextile at the end of this test, together with the specific application of the geotextile, will define the length of the time that the material may be exposed on site. The maximum exposure times are given in Table 3.

Extended testing is necessary for materials which are to be exposed for longer durations.

Table 3

Application	Retained strength after weathering test	Maximum time of exposure during installation
reinforcement or other applications where long-term strength is a significant parameter	>80%	1-4 months[1)]
	60-80%	2 weeks
	<60%	cover on day of installation
other applications	>60%	1-4 months[1)]
	20-60%	2 weeks
	<20%	cover on day of installation

[1)] depending on the season and the location in Europe.

Extended artificial weathering tests using methods similar to those in ENV 12224 are required for materials which are to be exposed for longer durations.

If the materials are to be used for reinforcement an appropriate partial safety factor should be applied to allow for the reduction in strength.

7.3 Resistance to chemicals

7.3.1 General

For geotextiles exposed to soil for a period of up to 25 years the following forms of chemical degradation should be considered:

- alkaline attack on polyesters (see 5.2.2);
- acid attack on polyamides under aerobic conditions;
- oxidation of polypropylene and polyethylene;
- internal hydrolysis of polyesters in water or any aqueous solution.

7.3.2 Resistance to alkalis and acids under aerobic conditions

Acid and alkaline attack on geotextiles are covered by screening test WI 00189029. Method A is a screening test intended for geotextiles for use in acid soils with pH<4 under aerobic conditions. The retained strength should exceed 50% of the initial tensile strength.

Method B is a screening test for geotextiles for use in alkaline soils with pH>9, lime treated soil, cement and concrete. The retained strength should exceed 50% of the initial tensile strength.

It has been shown that these tests are repeatable, reproducible and can be used to rank materials. If a material passes the criterion for Method B, its performance could be estimated to be satisfactory for up to 25 years at a temperature of 25°C for pH10. Otherwise, interpretation of either test should be viewed on a site specific basis and further advice should be obtained. For the use of polyamides under acid aerobic conditions (7 < pH < 4) assurances should be sought from the manufacturer that the material has a sufficient level of resistance.

These two tests are not intended to cover all chemicals (see 7.3.5).

7.3.3 Oxidation

Polyolefins such as polypropylene and polyethylene are susceptible to oxidation and therefore all such materials should be subjected to the accelerated thermal oxidation screening test WI 189027. The type of polymer used and the specific application of the geotextile will define the length of time and the temperature that the material has to be exposed to the oven ageing. For all applications the retained strength should exceed 50% of the tensile strength of the reference samples (see Table 4).

Table 4: Parameters for the screening test for resistance to oxidation

Application	Polymer Type	Oven exposure temperature	Oven exposure time	Retained tensile strength
reinforcement or other applications where long-term strength is a significant parameter	polypropylene	110°C	28 days	≥ 50%
	polyethylene	100°C	56 days	
all other applications	polypropylene	110°C	14 days	≥ 50%
	polyethylene	100°C	28days	