11

Natural geotextiles

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11.1 Introduction

Geotextiles is a compound word, ‘geo’ and ‘textile’, which means fabrics used in association with soils during ground engineering. Natural geotextiles is a shortening of the phrase ‘natural-fibre geotextiles’, meaning, therefore, textiles that are made from natural fibres and used in association with soils.

It is believed that mankind’s cultural history began around 10,000 to 12,000 years ago [1], when nomadic tribes developed from living the forager–hunter existence, following the natural migration of wild herds, to establishing early farming practices of domesticating animals and cultivating plants. Besides being used for fuel in cooking and keeping warm, fibrous materials would have then found particular applications, not only in the building of shelters and fences, but also in the construction of pathways, where soft soils would have been reinforced with logs of wood, branches hand woven together, bamboo, straw, reeds and stones. It could well be argued that the use of bamboo, straw and reeds woven into sheet materials was one early application of primitive forms of natural geotextiles. It is believed that the biblical ‘tower of Babel’ was built on a substrate, reinforced by woven river reeds [2]. Records also show that as far back as the fifth millennium BC, the then Persians used fibrous sheet materials for soil reinforcement to increase the stability and longevity of pathways [3]. The construction of reinforced clay installed along the banks of the Tigris and Euphrates occurred in the third millennium BC. Some 3,000 years ago in ancient Egypt straw was also used to reinforce clay for building walls and footpaths.

Hemp is one fibre type used today for producing modern natural geotextile products; this plant is considered native to Central Asia and was subsequently introduced into China where for over 4,500 years it was grown for a wide range of end-uses including geotechnical applications. Thus, in their various primitive forms, natural geotextiles existed for many years.

The systematic application of geotextiles began around the late 1950s, largely with the development of synthetic fibres. Initially, woven fabrics were mainly employed in the construction of river and waterway bankings to prevent erosion of sandy soils behind stone barriers. In the mid-1960s other textile materials, referred to as nonwoven fabrics, became important and widened the end-uses for geotextiles. Today, for many geotechnical applications, these various textile forms are employed in combination with plastic sheet materials, termed geomembranes, in particular high density polyethylene (HDPE). The majority of textile fibres utilised are synthetics, mostly poly(propylene) (PP), poly(ethylene) (PE), and polyester (PET). Thus, the term geosynthetics is used to distinguish between materials made from synthetic fibres and polymer sheets and those made from natural fibres.

The biodegradability of natural fibres has led to a resurgence of their use in geotechnical applications where non-permanent man-made structures are needed to temporarily protect and enable the natural growth of local foliage in land and waterway reclamation, restoration or development. Natural geotextiles are being widely used for short-term (6-months to 10-year) applications where biodegradability is a positive attribute.

This chapter describes the types of natural fibres that are used for biodegradable geotextiles, the important properties of these fibres, the process and structures of the textile forms into which they are converted, and most importantly their geotechnical end-uses. First, however, it is necessary to understand what geotextiles are, and also their primary functions.

11.2 Fundamental aspects of geotextiles

11.2.1 Definition and terminology

Geotextiles are permeable textiles used with foundation soil, rock, earth or other geotechnical engineering related materials as an integral part of a man-made product, structure or system [4]; they are made from both natural and synthetic fibres. In contrast to geotextiles, geomembranes are synthetic liners which are impermeable to both fluids and particles [5]. Between these two extremes are grids, nets and mesh structures, and laminated combinations of the various groups that are called geocomposites. Since here we are only concerned with natural geotextiles, readers interested in the wider subject of flexible geomaterials are referred to references [6,7].

11.2.2 Functions of geotextiles

Geotextiles essentially have five functions:

1. *Fluid transmission*: a geotextile can be constructed to enable a liquid or a gas to flow, usually lengthways, within the plane of the fabric. A typical example is the use of a geotextile to drain excess water in soils to reduce

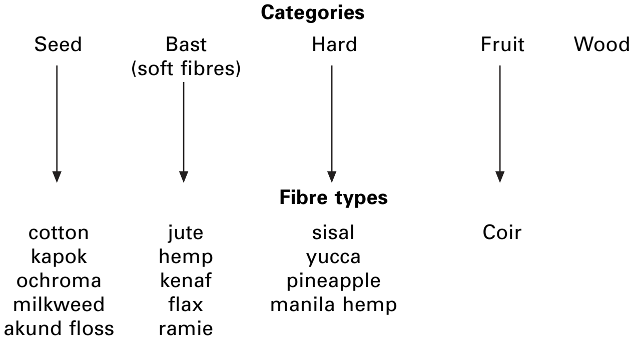
the pore water pressure and increase the loading capacity or rigidity of the soil, i.e. the compressive modulus. The important property of a geotextile for fluid transmission is its in-plane water permeability, more technically referred to as its transmissivity.

2. *Filtration*: geotextiles may be used as filters by permitting liquids to flow through the plane of the structure (the flow is assumed normal to the fabric surface), whilst preventing soil particles from being carried away by the liquid flow, i.e. stopping liquid transmission of particles through the fabric. The through-plane permeability, more technically termed the permittivity, and the pore size characteristics are indicators of a fabric's effectiveness as a geotechnical filter.
3. *Reinforcement*: compacted soils and aggregates have good compressive modulus but poor tensile modulus and consequently can be readily separated when subjected to sizeable tensile loads. Employing fibres of appropriate tensile moduli, geotextiles become effective reinforcing tension elements when embedded in compacted soils and aggregates.
4. *Separation*: placed between two layers of soil or granular material of differing particle sizes, a geotextile with suitable pore size characteristics would form a barrier to the migration of particles from one layer to another.
5. *Protection*: a geotextile can be constructed to have good resilience and thermal insulation. Its compressive properties are often utilised in puncture protection of membranes by placing the geotextile as an intermediate layer between, say, a stony soil base and a membrane covering. When used in the control of surface soil erosion a geotextile, in addition to other functions, provides protection to seedlings until the vegetation becomes established.

Generally in any given application, a geotextile performs one or more of the functions described, and illustrations are given for natural geotextiles later on in this chapter.

11.3 Fibres used for natural geotextile products

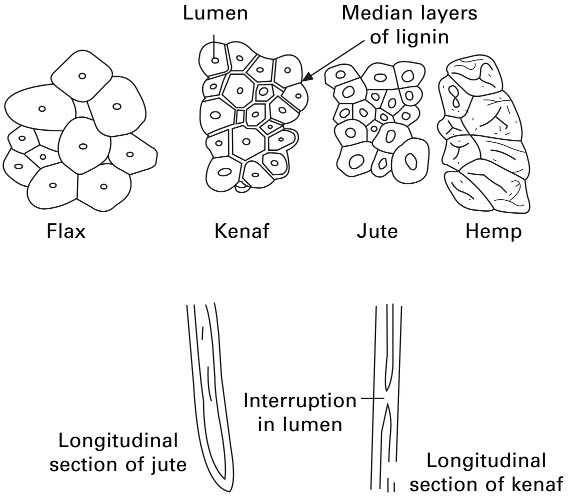
The fibres used for natural geotextile products are plant or vegetable fibres, although some research and development studies have considered the use of very low grade sheep's wool and wool waste. Figure 11.1 shows a classification of well known natural fibres. However, the only ones that meet with the technical requirements, cost effectively, are the bast fibres: jute, hemp, kenaf and flax (also called soft fibres because they are from the softer region of the plants), and the hard (or leaf) and fruit fibres: sisal and coir. Others of the remaining fibres, e.g. wood fibres, are sometimes used as fillers within the textile structure.



11.1 Classification of natural organic fibres.

11.3.1 Morphology

All plant species are built up of cells and when such cells are very long in relation to their width they tend to form fibres. The cells of the fibres used in natural geotextiles are like microscopic tubes, having a thick wall surrounding a central void termed a lumen. Figure 11.2 illustrates some cross-sections of natural geotextile fibres and the microscopic tubular shape of the cell with lumen centres can be seen, particularly in respect of the bast fibres. Strictly, the cells are polygonal in outline having sharply defined angles, depending on fibre type; for example, jute and kenaf compared with flax and hemp are more angular. Table 11.1 gives examples of cell and fibre dimensions. From Fig. 11.2 and the data in Table 11.1, it can be understood that fibres comprise aggregates or bundles of cells held together by median layers of lignin, the



11.2 Illustration of the cross-sectional features of bast fibres.

Table 11.1 Fibre dimensions

Fiber type	Cell width (μ)	Cell length (mm)	Mean aspect ratio	Fibre width (μ)	Fibre length (mm)
Jute	20–25	1.3–4.8	90		1500–3600
Hemp	16–50	4.8–54.9	1000	10–100	1000–4000
Kenaf	14–33	2.0–6.1	200		1500–1800
Flax	11–20	10.9–37.8	1000	4–600	250–1200
Sisal	10–48	1.0–4.8	100		
Coir	12–24	0.3–1.0	30		150–300

fibre lengths being formed by overlapping cell lengths. The number of bast cells in an aggregate governs the fibre thickness or diameter and may vary from 3 to 20 depending on fibre type. However, the dimensions of the fibres are not only dependent on the cell dimensions, but also on the processes used to extract the fibres from the original plant and convert them into a useable form. These processes are described later.

Fibres can be processed to be finer and shorter than the figures given in Table 11.1, so as to meet end-use requirements. The ultimate fineness and length would approximate closely the cell dimensions, suitable as paper-making pulp. Thus, the average ultimate fibre length of flax would be 25 to 35 mm; jute, on the other hand, would be 2 to 3 mm.

Generally, raw materials of finer and longer fibres, with narrow fineness and length distributions, are more beneficial to the manufacturing processes used to produce textile fabrics, and also the overall quality of the fabrics produced is better [8, 9, 10]. For example, the finer and longer the fibres are, the finer and stronger the yarns that can be spun to produce lighter and/or stronger woven fabrics. This is because, in addition to the twist inserted to make a yarn, the number of fibres in the yarn cross-section and the overlapping lengths of such fibres govern the yarn tensile properties [8]. Thus, the monetary value of a given raw material is determined by the dimensions and uniformity of the mass of fibre extracted from the plants. Where fibres are used to make a nonwoven sheet or mat, then for a given fibre type, coarser and therefore cheaper fibres may be more cost effective.

11.3.2 Chemical and physical properties

The fibres used for natural geotextiles are effectively cellulose reinforced materials as their physical structures comprise cellulosic microfibrils, running along the fibre cell length, contained in an amorphous matrix of hemicellulose and/or lignin; from the viewpoint of their chemical grouping, they are called lignocellulosic fibres. The cellulosic polymer structure and the hydrogen bonds linking the polymer chains give strength and stiffness to the fibres.

The lignin and hemicellulose polymers are responsible for such physical and chemical properties as biodegradability, flammability, sensitivity towards moisture, thermoplasticity, and degradability by UV-light [11]. (See Table 11.2).

Table 11.2 Chemical constituents controlling fibre physical properties [11]

Constituent	Physical properties
Cellulose	Tensile Moisture absorption
Hemicellulose	Biodegradability Thermal degradability Moisture absorption
Lignin	Thermal stability UV degradability

Source: ref. 11

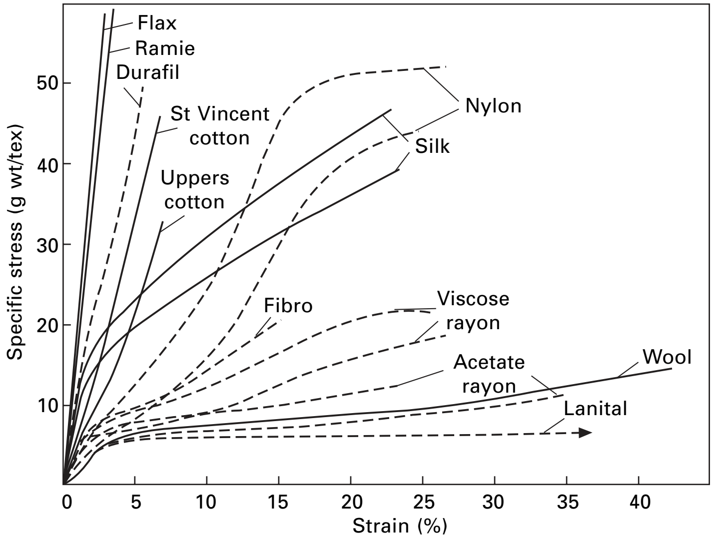
Table 11.3 gives the relative proportions of the chemical constituents for each type of natural fibre commonly used for geotextiles. These fibres can have moisture contents of up to 20% by weight. The constituents of the fibres determine the interaction between the geotextiles and their immediate environment and therefore the longevity of the geotextiles will depend on the amount of cellulose and lignin present in the constituent fibres; the greater the amount, the higher the endurance. Coir has the highest resistance to biodegradation.

Table 11.3 Comparative chemical composition

Fibre	Cellulose (%)	Hemicellulose (%)	Lignin (%)
Bast fibres			
jute	70–75	12–15	10–15
hemp	68–85	10–17	10.6
kenaf	60.8	20.3	11
flax	70–78	9–10	3–8
Hard fibres			
Sisal	73		11
Fruit fibre			
Coir	35–45		40–45

Source: Danforth International and TAPPI

Figure 11.3 depicts the tensile behaviour of some commonly known natural and man-made fibres. The bast fibres (flax and ramie) show that a high specific stress is required just to obtain a relatively small strain, whereas wool, say, extends readily with much lower specific stress. The bast fibres show no yield point and brittle fracture. Wool in contrast shows a definite yield point. Clearly the higher resistance to extension is useful for temporary reinforcement of soils, where the intention is for vegetation growth to ultimately replace this reinforcement function of a geotextile embedded in the soil. Until the vegetation is established, the geotextile will prevent significant movement of the soil under load; for example, slippage of newly laid soil on a slope. An important property in such applications is the initial modulus (E-modulus) of the natural fibre, and Table 11.4 enables a comparison to be made with E-glass, which is widely used as a reinforcing fibre for industrial applications. It is evident that excepting for coir, the tensile properties of the other fibres used in geotechnical applications compare favourably with those of glass, in particular their specific modulus. This means that for the same fabric structure and mass per unit area, these natural fibres should be at least as good as glass as reinforcing materials, in fact flax would appear to out-perform glass. However, the usefulness of these fibre properties will depend on the effectiveness of the interfacial bonding between the reinforcing fibre and the matrix. For soils, the moisture regain of a fibre is a useful property for initiating good interfacial bonding, and where restoration of vegetation is also a requirement, retention of moisture by the geotextile is advantageous.



11.3 Examples of stress strain behaviour of natural and manufactured fibres.

Table 11.4 Comparison of fibre properties and estimated cost

Property	Fibre type								
	E-glass	kenaf	flax	hemp	jute	ramie	coir	sisal	cotton
Density (g cm^{-3})	2.55	1.4	1.4	1.48	1.46	1.5	1.25	1.33	1.51
E-modulus (GPa)	73	53	60–80	70	10–30	44	6	38	12
Specific modulus (N/tex)	29	38	43–57	47	7–21	29	5	29	8
Tensile strength* (MPa)	2400	930	800–1500	550–900	400–800	500	220	600–700	400
Specific strength (cN/tex)	94	66	57–107	37–61	27–55	33	18	45–53	27
Elongation at failure (%)	3		1.2–1.6	1.6	1.8	2	15–25	2–3	3–10
Moisture absorption (% by wt)	–		7	8	12	12–17	10	11	8–25
Price/kg ($), raw	1.3		0.5–1.5	0.6–1.8	0.35	1.5–2.5	0.25–0.5	0.6–0.7	1.5–2.2

*Influenced by number of cells in cross-section of industrial fibre

The data in Table 11.4 show that moisture absorption (regain [12]) of the fibres concerned is within the measured range for various varieties of cotton. In this respect, ramie would technically seem to be a useful fibre for geotechnical application. However, its material cost would appear to preclude it from such end-uses.

11.4 Fibre extraction and preparation

The fibres that were described above as being used for natural geotextiles, are usually extracted from four varieties of the woody-stemmed herbaceous dicotyledons (i.e. the bast fibres flax, jute, hemp and kenaf), one of the monocotyledonous plants (i.e. sisal) and one of Palmaceae (palms) (i.e. coir) [13, 14].

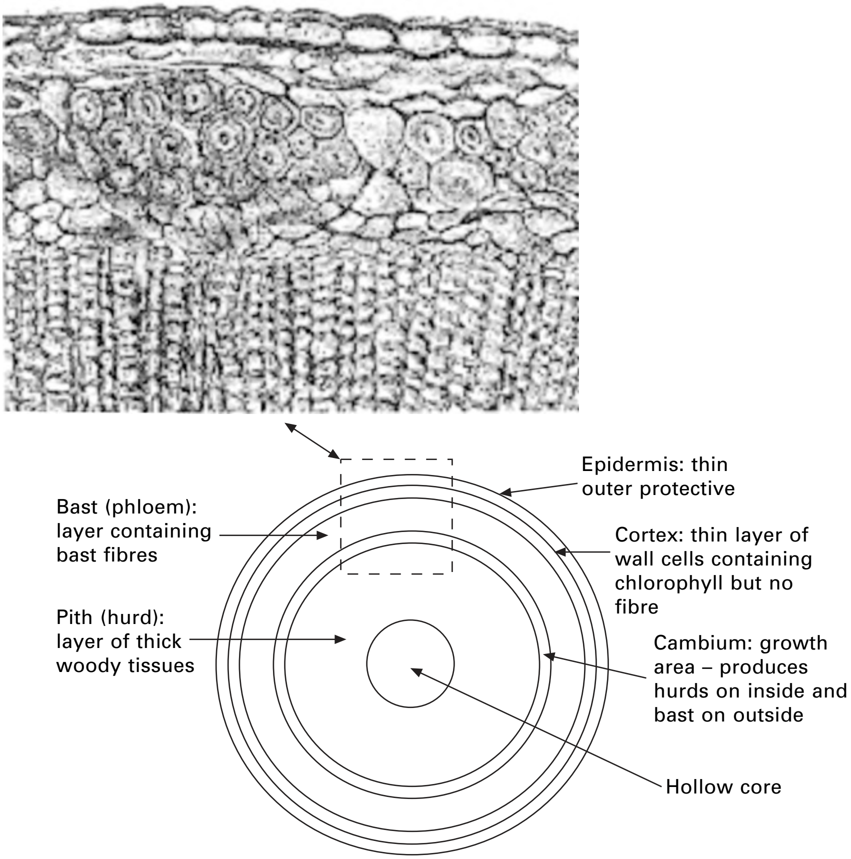
11.4.1 The bast fibres

Figure 11.4 illustrates the typical cross-section of annually grown dicotyledonous plants. Bast fibres are obtained from the fibrovascular bundle region, known as the bast (or phloem), located between the bark (or epidermis) and the hurd (or pith). Each plant is made up of approximately 30% bast and 60% hurd; the bark, cortex and cambium accounting for the remaining 10% [15]. As described earlier, a bast fibre comprises overlapping bast (or sclerechymous) cells, thereby effectively forming a continuous filament.

These fibre-containing plants have their own distinctive attributes and Table 11.5 gives a short account of these, also the principal producing countries and the relative percentages of the global production of natural organic fibres used commercially.

All bast fibres are extracted from their plants by a retting process which frees the fibre from the hurd and is then followed by scutching to separate and remove the fibres from the bark and hurd.

Retting is the bacterial decomposing of the natural glues that adhere the bast fibre to the hurd. Traditionally this is accomplished in one of two ways; either dew-retting or water retting. With the former, the swath of stem material, after mechanical harvesting, is left for about 4–6 weeks in the field for dew and rainfall to affect the process; however, prolonged excessively wet conditions can turn retting to rotting. Owing to the vagaries of weather and the need to speed up the process water retting was developed. Here, the sheaves of cut plants are immersed, root downwards, into tanks and covered. The water is kept at approximately 35°C and circulated through the mass of material. After retting is completed the sheaves are removed, drained and left to dry in the field, termed 'gassing'. When the crop is dried to less than 10% moisture content it can be stored ready for scutching. It is claimed that water retting produces a more uniform and higher quality fibre but the process is



11.4 Morphology of bast fibre plant.

time consuming and costly and can pollute the body of water being used for the process.

Various newer technologies have been developed to speed up the process of fibre extraction such as chemical retting, using glyphosate and Diquat, and mechanical retting or decortication which mechanically separates the bast from the hurd without the additional scutching. Steam explosion, detergents and ultrasound are other methods being tried.

Scutching is a process in which the retted plant is separated or ‘transformed’ into its basic parts: the hurd and the bast fibre. While transforming the plant, the fibres are kept at full length so at the end they can be cut to the length required for further processing (i.e. length needed for paper making, spinning/ weaving, or nonwovens used in composites and geotextiles).

The scutching operation usually involves four stages: rough scutching, shaking, fine scutching, and cutting and baling [16]. In the first stage of the process line, layers of the retted plant are presented via feed rolls to a

Table 11.5 Fibre-containing dicotyledonous plants

Fibre type	Dicotyledon species	Principal producing countries	Attributes	Percentage of global natural organic fibre production (%)**
Flax	*Linum usitatissimum*	China, France, Romania, Belarus, Netherlands	Plant reaches 1 m in height [2] with a slender stem and sky blue or white flowers	3.2
Jute	*Corchorus capsularis* (also called Jew's mallow)	China, India, Bangladesh	Plants range from 9–19 mm in diameter and 1.5–3.7 m in height, with small yellow flowers	14
Hemp*	*Cannabis sativa*	Russia, Ukraine, Poland, Hungary, Yugoslavia, Romania, France, Italy, UK, China, Germany, Africa, Canada	The plant is cultivated similar to flax and reaches a height of 1.2–3.7 m with yellowish green flowers	0.09
Kenaf	*Hibiscus cannabinus*	Indigenous to Africa, but also grown in India, China, The Commonwealth of Independent States, Iran, Thailand and the USA	Mature plants grow to 2.5–6 m in height with yellowish flowers	

*Conventional plant breeding has enabled the virtual elimination of the psychoactive drug THC, tetrahydrocannabinol, from the genus
**Cotton accounts for 71.8%, wool 8.10%, silk 0.04% and ramie 0.04%

rotating drum with spring steel blades mounted on its outer circumference. The circumference of the feed rollers is profiled to crimp the plant along its length, thereby breaking up the hurd without damaging the fibres. Then, as the material passes the steel blades while moving with the rotating drum, the pieces of broken-up hurd (or shives) are scraped from the fibres; on the whole fibres suffer little damage. The second stage involves the use of shaking screens which, as the name implies, shake up the material while transporting it to the third stage with the result that loose shives fall out from the fibres. At the third stage, a similar scutching unit to the first stage is used. The steel blades are, however, set closer to the drum, so that now the finer fragments can be scrapped from the fibres.

The cleaned fibres would still retain their full lengths, so that at the final stage they can be cut to size, as required. After cutting, the fibres are baled by an automatic hydraulic baling press ready for the subsequent manufacturing processes.

Grading of the bast fibres, as well as of sisal and coir, is well explained in the cited literature [12, 13, 14]. However, in general, there are three classes of fibre [17]:

1. Primary fibres: these are long and low in lignin and are the strongest and most valuable.
2. Secondary fibres: medium in length and higher in lignin.
3. Very short fibres: this type of fibre is often referred to as tow.

The primary class is seen also as the ultra-cleaned material. Cut lengths can be from 13 mm to 152 mm long, and can be suitably converted into nonwovens, woven textiles and composites products for the automotive, furniture, and construction industries. The secondary and very short fibre classes are general purpose grades having 50–70% cleaned fibre. These are used for hydro mulch, as cement fillers, in insulation and for geo-matting.

11.4.2 Hard fibres

Hard fibres (also termed leaf and structural fibres) are larger and stiffer than bast fibres, hence the name. They grow throughout the leaves or stem of monocotyledonous plants and like the bast fibres they give rigidity to the plant and also transport water and plant food from one part of the plant to another.

Sisal (*Agave sisalana*) is the most important species of hard fibre and is used for natural geotextiles as well as other industrial products. It is grown in Java, Africa and Haiti and accounts for about 1.5% of the world total natural fibre production. The leaves are harvested and subjected to a decortication process in which the epidermis and pulp are scraped from the fibre whilst simultaneously being washed. The resulting fibre mass is then dried and baled.

11.4.3 Fruit fibres

Coir fibres (*Cocus nucifera*) are obtained from the shells of coconuts. Traditionally, the nuts are firstly soaked in sea water, which softens the husks, after which they are manually beaten and washed with fresh water. The residual reddish brown fibrous mass is decorticated by tearing and hackling it into fibres, about 250 mm in length.

The industrial process involves initially splitting the fruit into quarters and weighing down these parts into large holding tanks of water for around 5 days. The husks are then removed and run through a machine with corrugated crushing rollers, called a ‘breaker’. The crushed fibrous mass is passed to a second stage where two machines in sequence, called ‘drums’, separate the fibres from the woody husks. The drums, 1 m diameter rollers × 355 mm width, are studded with spikes. The husks are held against these rotating drums enabling the spikes to remove the woody part, leaving the fibres to pass through the process line. The first drum would have the spikes spaced to give a coarse treatment, i.e. removal of larger broken pieces of husks, whilst the spikes of the second drum are more closely spaced for removing the finer husk fragments. The fibres are subsequently washed and dried and further hackled by combing with steel spikes and converted into hanks of tows. The tows are baled by a hydraulic press ready for transport to the spinning and weaving mill or the nonwoven plant.

11.5 Production of natural geotextile products

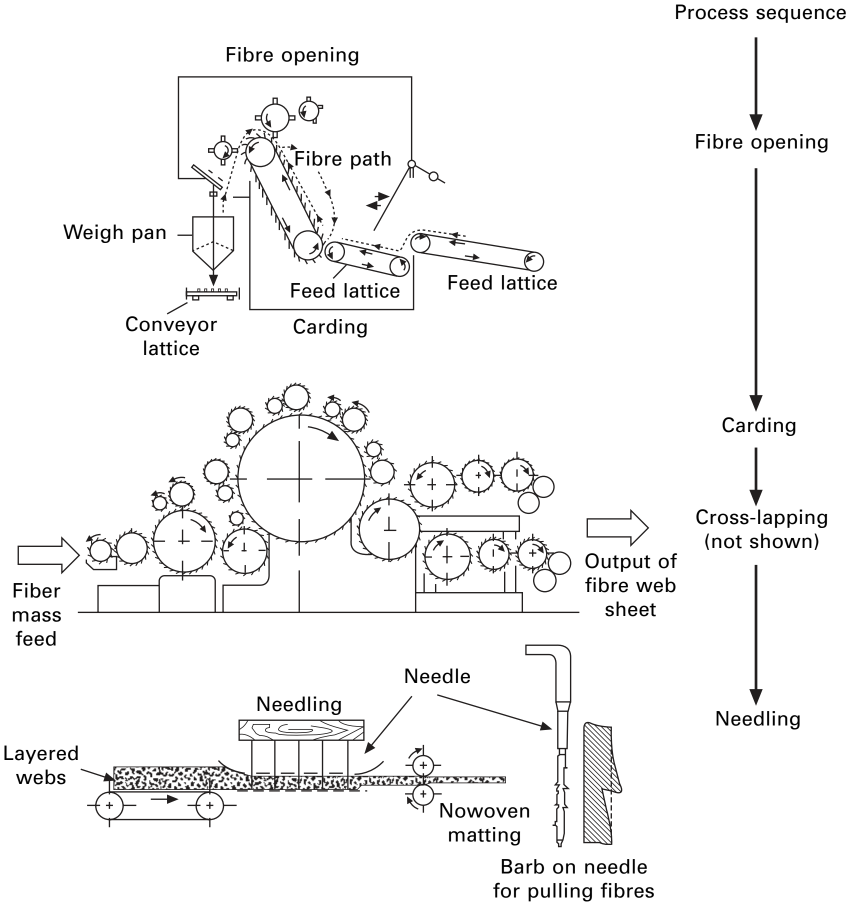
Natural geotextile products are usually manufactured in the form of a nonwoven matting (felt or mattress), or as a woven sheet of fabric or netting, and also as combinations of woven and nonwoven. For certain requirements a woven net may be converted into a cylindrical mesh which is then stuffed with fibres to form a geotextiles log. These logs or rolls are often used for erosion control of river embankments, as they provide initial structural stability by resisting wave action and flow velocity; also young seedlings may be planted in them for restoration of river-side vegetation. By slowing the water flow near the banking, sediment is deposited in and around these rolls to create an environment for vegetation growth. Having the slowest rate of biodegradation, coir is a suitable fibre from which to produce such bio rolls or bio logs.

The process technologies for producing nonwoven and woven fabric are already well described in the widely available technical literature on textile technology or textile engineering. It is therefore appropriate to restrict our considerations in this chapter to a general overview for the reader unfamiliar with the subject area, while citing suitable references for further study.

11.5.1 Production of nonwoven mattings

A nonwoven is a textile structure in the form of a flexible sheet that principally consists of a combination of several layered webs of fibres, which is given cohesion by some means of bonding the fibres together [18, 19, 20]. For the vast majority of natural geotextile mattings, bonding is achieved through mechanical entanglement of the constituent fibres comprising the structure, thereby utilising inter-fibre friction to obtain the cohesion.

Figure 11.5 illustrates the process sequence for producing natural geotextile mattings. Following the opening of fibre bales, a web of fibres is produced at an early stage in the process line known as carding. The card consists of a series of paired large and small rotating rollers; each covered with sharp points, the purpose of which is to separate the fibre mass into individual



11.5 Illustration of the process stages for nonwoven matting.

fibres so as to produce the web of fibres at the output section of the card. A subsequent stage, termed cross-lapping, forms the layered structure with the fibre web. Fibre entanglement is achieved by rows of long barbed needles repeatedly penetrating the thickness of the layered webs, and in so doing, each needle pulls fibre lengths from an upper layer through the layers beneath, with the ends of these lengths finally protruding out of the bottom surface of the sheet. This final stage is known as needle punching or needling, and is performed on what is called a needle-loom. Needling not only gives cohesion and strength to the nonwoven, but also decreases the fabric thickness and increases its density through greater compaction of the fibres. Thus, the degree of needling, specified as punches per unit area, along with fibre length and fineness, and the mass per unit volume of the cross-laid intermediate are important process parameters. Needling can be accomplished from both top and bottom surfaces of the layered fibre mass to give greater cohesion, compaction and stiffness to the resulting fabric.

If the nonwoven geotextile is to be used as a mulch,[1] then plant seeds can be introduced into the fibrous web prior to needling. The fabric would thereby act as a vehicle for the distribution of seeds in the soil and prevent erosion during seed establishment and early plant growth. Suggested insertion rates range from 2000 to 4000 wildflower seeds per m^2 for fabrics of 340 to 680 $g\ m^{-2}$.

11.5.2 Production of woven fabrics

The fibres must first be spun into yarns [21, 22]. To do so the baled material is opened and carded in a similar manner as described above, but instead of the carded web being cross-lapped, it is consolidated into the form of a twistless rope called a sliver. Usually two carding stages are used: the sliver from the first, so-called breaker card is then fed to the second, 'finisher', card. A two-carding operation enables gentle treatment of the fibres with effective extraction of any remaining shive fragments whilst maintaining a high production rate.

Figure 11.6, which is a flowchart of the process sequence, shows that the carded sliver passes through what is termed 'drawing' or 'gilling'. Often three drawing stages are used. This basically involves three machines (drawframes or gill boxes) that attenuate a group of slivers, each of the same known mass per unit length, down to one output sliver having the equivalent mass per unit length as an input sliver. Thus, if eight slivers were fed to a gill box the attenuation (i.e. 'the draft') would be eight. The figure shows the principle of how the gill box attenuates the material. Essentially, the output

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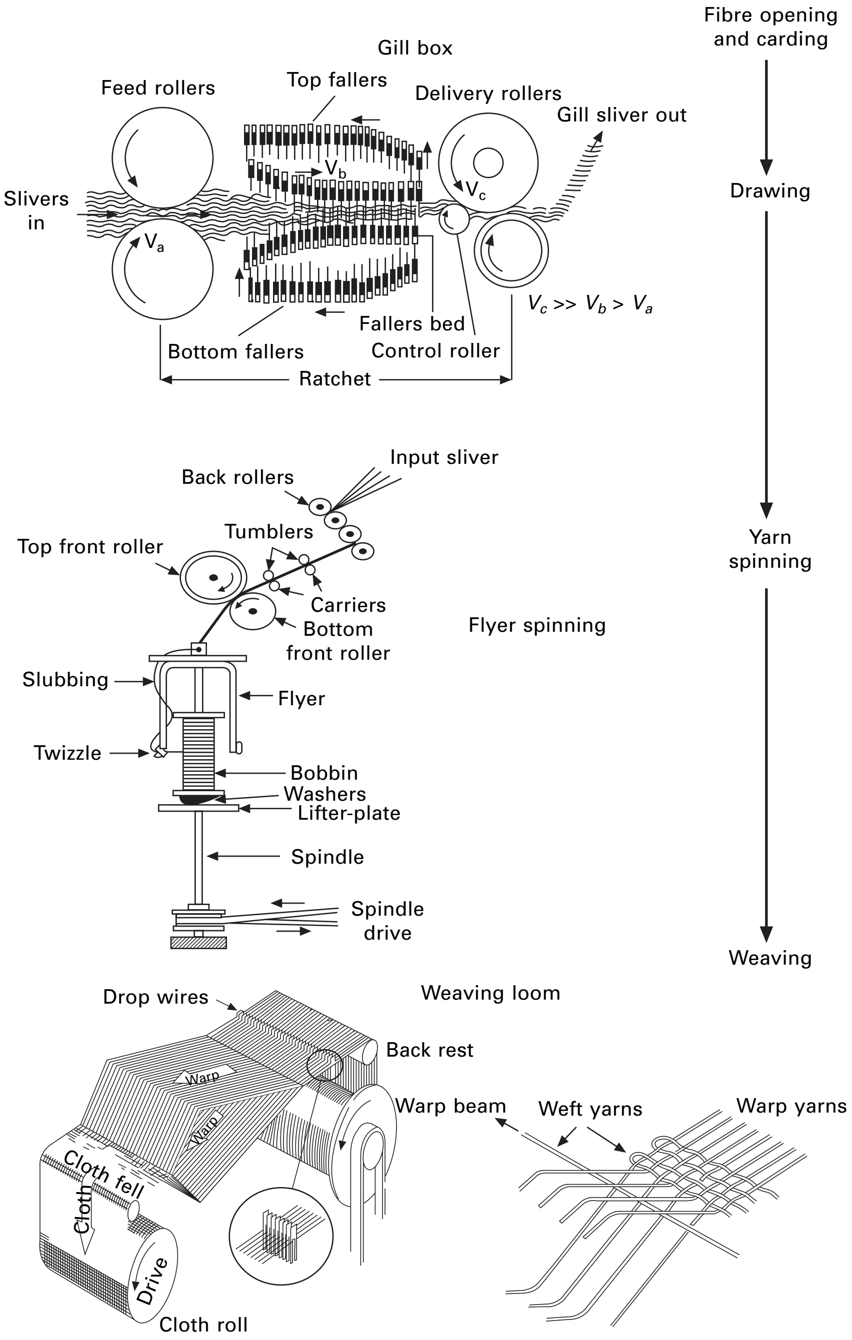
[1] A mulch is defined as 'an application or creation of any soil cover that contributes a barrier to the exchange of heat or vapour'.



11.6 Conversion of fibre to woven fabric.

front rollers are made to rotate with a surface speed eight times as fast as that of the input, back rollers. The front rollers are positioned so that their distance from the back rollers (termed the ratchet) is slightly longer than the maximum fibre length. Thus, as fibres are fed towards the front rollers, the leading ends of those reaching the nip of the front rollers will have their trailing ends released from the nip of the back rollers; these fibres can be pulled away by the front rollers at eight times the speed of those still nipped by the back rollers. The action is called drafting and this causes the attenuation. The movement of the fibres during the drafting process is controlled by gill pins, hence the term ‘gilling’.

In a three-stage drawing sequence, then, eight output slivers from the first drawing stage would be fed to the second, intermediate, drawing stage and eight from the second stage to the third. It is evident that at the first stage the output sliver comprises one-eighth of each input sliver, and that essentially these are combined to give the output sliver; the effect is referred to as a doubling of eight. This gives a mixing of the input slivers, so the result is termed blending by doubling. A simple calculation based on this eight-sliver feed would show that with three-stage drawing, a doubling of 512 would be obtained, giving a high degree of blending. Owing to the variation in properties between even fibres of the same type, blending is important in order to achieve consistent yarn properties.

The output sliver from the third, or finisher, drawing stage is passed to the spinning frame where it is attenuated, without doubling, at a very high draft needed to attain the much lower specified mass per unit length for the yarn. As illustrated in Fig. 11.6, drafting is now carried out with two pairs of small rollers, called tumblers and carriers, controlling the fibre movement in the drafting zone, replacing the gill pins, so that high drafts can be applied effectively.

Twist is inserted into the ribbon of fibres issuing from the front roller of the drafting system to form the spun yarn. The twisting mechanism widely used for spinning these plant fibres is referred to as the flyer and the action as flyer twisting or flyer spinning. The illustration in Fig. 11.6 is one example of flyer spinning. It can be seen that the newly formed length of yarn passes around one leg of the fly (mounted on a spindle), through a twizzle in the flyer leg and then onto a bobbin. As the flyer rotates twist propagates up the already formed yarn travelling down the flyer leg and into the fibre ribbon; one flyer rotation inserts one turn of twist. The spun yarn is simultaneously wound onto the bobbin through a combination of bobbin inertia and the frictional drag of the felt washers, positioned at the bottom end of the bobbins.

If required, two yarns may be twisted together to achieve increased yarn strength and to produce a heavier woven fabric. The resultant yarn is called a two-fold, a doubled or a plied yarn and its linear density would be twice that of the individual component yarns.

Figure 11.6 also illustrates how the spun yarns are employed in weaving a fabric. One set of yarns would be used as a warp (i.e. giving the length of the fabric) and the other as the weft (i.e. giving the width). The mechanical action of looms is well reported in the cited literature [23, 24]. Here, we will therefore consider certain basic parameters of importance to the properties of woven natural geotextiles.

It should be evident that from the view point of the fabric construction, the number of warp yarns per unit length across the fabric width (referred to as ends per cm) will govern the fabric strength in the length direction. Similarly, the strength in the width direction is dependent on the number of weft yarns per unit length (picks per cm). The generally used terminology is to call the number of warp yarns the number of 'ends' and the number of weft yarns, the number of 'picks'. Thus, with regard to fabric construction the number of ends and picks per cm squared is of importance to the strength of the fabric.

The strength of the fibres must be, of course, effectively utilised by the spun yarn. A yarn can never have the same strength as its constituent fibres because of the fact that to withstand an applied load, the yarn depends on the frictional contact between the overlapping lengths of fibres to transfer the load to all the fibres. The higher the twist the better the frictional contact and the stronger the yarn, but for each fibre type there will be an optimum twist to obtain maximum yarn strength [8].

In addition to tensile strength, as explained in Section 11.3.2, the tensile modulus of the fabric can be equally important. Contradictorily, as twist is increased to achieve better yarn strength, the effective conversion of fibre modulus to yarn modulus becomes poorer. The yarn modulus therefore decreases with twist and this will be reflected in the fabric. Another important factor is the fabric crimp.[2] This is the undulations a weft yarn, say, has owing to its interlace with the warp yarns, and it would be called the weft crimp of the fabric. The crimp means the constituent yarn lengths are greater than the linear fabric dimensions. Thus, if L is the measured weft yarn length in a metre square sample of a fabric, then the increased length as a percentage of the sample width is called the percentage crimp and is calculated by equation:

$$\%\ \text{crimp} = (L - 1)\ 100 \tag{11.1}$$

Both weft and warp crimp of a fabric are important to the fabric modulus [25], in that the higher the crimp is, the lower the modulus will be.

From what has been discussed above it can be reasoned that the fabric mass per unit area will be governed by the number of ends and picks per unit area; the value of weft and warp crimp; and by the mass per unit length of

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[2] The waviness or distortion of a yarn that is due to interlacing in the fabric.

the weft and warp yarns. The latter parameters are commonly called the yarn count. The International Standard unit for yarn count is the tex, which is the number of grams that a 1000 metre-length of yarn weighs.

If N_p, C_p, N_t, C_t, are the above warp and weft parameters, then the total length of the warp yarns in a metre square fabric sample is:

$$= N^p (0.01C_p + 1) \tag{11.2}$$

and the total length of weft yarns

$$N_tL = N_t (0.01C_t + 1) \tag{11.3}$$

Let T_p and T_t be the counts of the warp and weft. The mass per square metre of the fabric (i.e. the basis weight in g m^{-2}) is equal to the sum of total lengths of warp and weft yarns, and can be calculated by

$$\text{Fabric Basis Weight} = T_pN_pL + T_tN_tL \tag{11.4}$$

The main purpose of a mulch is to control the environmental factors that affect seedling survival; e.g. moisture, temperature, light, chemical presence or absence, weeds and mechanical damage. The mulch also acts as a soil insulator to keep the soil warm in the early and late part of the growing season. It is also a vapour block to suppress evaporation and a weed suppressor so that saplings can make full use of light, moisture, and nutrients.

A mulch must therefore be as opaque as possible to prevent weed growth, possess good insulation characteristics and be sufficiently porous for water infiltration, yet retard water loss from underneath it. It needs to be strong and durable enough to last until seedlings are well established, usually about 3 years.

The open spaces of a fabric, formed by the interlacing of the yarn, are called the interstices and it is evident that the sizes of these depend on the spacing of the picks and ends, and the yarn diameters. The importance of the interstices is that they enable soil in which the geotextile is laid to become embedded into the fabric, thereby anchoring the reinforcing fabric. If the fabric is to be used as mulch for protection against soil erosion, then the interstices help to disrupt surface water flow and enable vegetation to grow through the fabric.

In practice, it is the area fraction covered by the yarns in a square metre sample of fabric that is specified and is termed the cover factor, K. The total open space of the fabric sample is then equal to 1–K. The cover factor is calculated according to

$$K = \frac{D_p}{S_p} + \frac{D_t}{S_t} - \frac{D_p}{S_p}\frac{D_t}{S_t} \tag{11.5}$$

where D_p and D_t are respectively the warp and weft yarn diameters, and S_p and S_t the average spacing between two ends and between two picks [24].

The rate of moisture absorption and biodegradability is primarily dependent on the chemistry of the fibre type, as indicated by Table 11.2. However, the twist of the yarn and the basis weight of the fabric can be used as moderating factors. The higher the twist, the slower the rate of absorption, and the greater the fabric weight, the lower the rate of biodegradation.

11.6 Measurement of the properties of natural geotextiles

From the point of view of product specification and quality assurance[3] the general practice is to adopt measurement procedures described in international standards (International Organisation for Standardisation – ISO) and European standards (BS EN), rather than national standards, excepting, that is, for the American Standard Test Measurements (ASTM) which, it may be argued, continue to take the lead in developing reproducible test procedures for geosynthetics, generally. The fundamental issues surrounding the use of standards for geosynthetics as a whole, including the sampling and preparation of test specimens (test standard BS EN 963: 1995), are well discussed by Koerner [6]. We will, therefore, only consider here the basics of the tests relevant to natural geotextiles in woven and nonwoven forms.

Based on the US Erosion Control Technology Council (ECTC) Guidelines and on published studies of natural geotextiles, the tests listed in Table 11.6 are important ones used in evaluating such products.

Table 11.6 Test methods for natural geotextiles

ISO	BS EN	ASTM	Description
	964-1:1995	D 5199	Nominal thickness
	965:1995	D 5261	Mass per unit area
10319: 1996*		D 5035	Breaking force and elongation
		D 4751	Apparent opening size
		D 5321	Shear friction
12958:1999*		D 4491	Water permeability
		D 6459	Erosion control blanket performance in protecting hillslopes from rainfall-induced erosion
		D 4355	Exposure to ultraviolet light and water
		D 5988	Aerobic biodegradation under controlled composting conditions

* BS EN ISO – i.e. European standard adopted by ISO

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[3] The verification of the conformance of materials and methods of application to the governing specifications, in order to achieve the desired result [25].

11.6.1 Nominal thickness and mass per unit area

The thickness of a geotextile is accepted as the calculated average of 10 measured specimens, each of 70 mm diameter taken randomly across the width of the fabric. Each specimen is, in turn, placed between two flat steel plates and the measurement made following an applied pressure of 2 kPa. Further measurements may be made at 20 and 200 kPa, and the three sets of values plotted so that the thickness under zero pressure can be extrapolated.

The specimens used for the thickness measurements may be weighed and the average value used to calculate the basis weight. However, it is more common to use 100 mm diameter specimens.

11.6.2 Breaking force and elongation

A basic tensile test is carried out on 200 mm wide specimens, using a rate of extension of 20% min^{-1}. The load-extension curve enables an understanding of the likely behaviour of the woven or nonwoven material, in respect of its initial modulus.

11.6.3 Apparent opening size

Several terms are used in geotechnical engineering to describe the pore size of fabrics, namely: apparent opening size (AOS), equivalent opening size (EOS) and filtration opening size (FOS). The terms are used with the symbol O_x, which refers to the pore size diameter which is greater than x% of the pore diameters contained within the fabric. Therefore O_{95} refers to the measured value of the 'near largest' pore diameter in the fabric; for the purpose of filtration it is necessary that O_{95} pore size enables adequate flow capacity, but yet prevents fabric penetration and migration of the majority of soil particles and minimises any tendency for clogging of pores. Consequently, the criterion for soil retention is commonly set as a ratio of the AOS to the particle diameter of D_{90}, D_{85} or D_{50}; for example, $O_{95}/D_{85} < 1$. Koerner [6] in a review paper on the subject summarises various soil retention design criteria.

The standard method used for determining O_{95} is referred to as the 'dry sieving method'. The fabric is clamped in a sieve frame, attached to a shaker, and 50 g of glass beads of a known diameter are sieved for 10 mins. The quantity of beads that passes through the fabric and that have remained on top of it are weighed; the difference indicates the amount trapped within the fabric. The procedure is repeated using successively larger diameter beads, until the mass that has passed through the fabric is 5%. The related diameter is equivalent to O_{95}.

11.6.4 Shear friction

For situations involving soil–fabric interaction on sloping surfaces it is often necessary to determine the soil-to-fabric interfacial strength. The test instrument is an adaptation of the direct shear box used in soil friction tests [6]. This consists of two parts, an upper and a lower box. The test specimen covers the face of the lower box and is securely held in place. The upper box initially rests on top of the lower box and is filled with soil which then makes full contact with the fabric surface. A normal pressure is uniformly applied to the soil in the upper box, and whilst the upper box remains stationary, the lower one is moved horizontally, under the applied normal pressure; this generates shear forces at the soil–fabric interface. To move the box, the force applied initially increases to a peak value and then decreases to a constant level with the displacement of the lower box. By repeating the procedure using increased normal pressures, a straight-line graph of peak shear force versus normal loading (i.e. the Mohr–Columb Envelope) is plotted to obtain the apparent cohesion and the friction angle (the tan Θ of the line gradient) [6].

11.6.5 Water permeability

Darcy's law is recognised as a principle governing liquid movement through a porous medium under conditions of laminar flow. The basic characteristic parameters of water permeability for geotextiles are permittivity and transmissivity, which are, respectively, the ease of flow of water, at normal angle, through the fabric surface, and the ease of flow within the plane of the fabric [6].

Water permeability is a principal property of nonwoven geotextiles used for filtration and drainage; however, when woven or nonwoven fabrics are used for mulches the permeability behaviour is less straightforward. Rainfall effects on slopes are of particular interest and the permeability of a fabric should relate to the amount of rainfall immediately available to seedlings.

Performance tests may be undertaken for a 30° slope angle. The test apparatus consists of a regulated sprinkler head and two tanks with tops cut at a 30° angle, one tank collects the water that passes through the mulch specimen of dimensions 28 cm × 28 cm, and is therefore covered with a 12 mm screen to support the specimen. The other tank collects the water run-off. The sprinkler head is set to a spray rate of 50 g min^{-1}. The basis weight of the mulch is determined before and after a set duration of spraying, and the water content in the two tanks is also measured, water not accounted for is designated 'splash'. The permeability of the mulch is then a measure of the amount of water that had passed through the fabric and would therefore have been available to seedlings; high run-off levels would indicate low water availability. Generally, most effective mulches have permeability values within the range of 25–60% water flow-through.

11.6.6 Erosion control blanket performance

Sediment resulting from water run-off on steep slopes can be detrimental to the free flow of waterways; most commercial natural geotextiles target this problem. One commonly accepted method for measuring the effect of a geotextile on erosion control involves a modification to the above procedure. A 1.2 m × 1.2 m specimen of the geotextile is placed on a soil slope and a measured amount of artificial rain applied to the slope. Sediment and water run-off are then collected and measured. This test is best conducted in the field where site-specific conditions, such as inherent soil type, can be considered.

11.6.7 Exposure to UV radiation

The UV spectrum may be subdivided into three wavelength bands: UV-A (400 to 315 nm), UV-B (315 to 280 nm) and U-C (280 to 100 nm). The radiation of the first causes a small amount of polymer degradation; that of the third is absorbed by the upper atmosphere, but the radiation of the second band is very damaging, breaking polymer bonds and weakening fibres.

Tests for the resistance to UV degradation involve exposing geotextile specimens to light from a xenon-arc lamp, simulating sunshine. Specimens are exposed for 150, 300 and 500 hours and the degradation of measured properties (e.g. strength and extension) determined. The test follows 120 minute cycle of which 102 minutes is exposure under dry conditions and 18 minutes under wet conditions.

11.6.8 Biodegradation

Soil contact test: here a defined sand/soil/mature compost matrix is employed to provide a consortium of mesophilic and thermophilic bacteria and fungi. Biodegradation is based on the amount of material carbon converted to gaseous carbon (CO). Materials that rapidly biodegrade can be completely tested in 30 to 60 days.

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