# Manufacturing process of geotextiles

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## 3.1 Introduction to geotextile manufacturing

The first textiles used in civil engineering projects were generally placed in soil for landscaping and building construction projects to stabilize and reinforce the soil. Over time, manufacturing processes for geotextiles have become increasingly specialized to the point of being a research field in its own right. As a result of technological research and development, geotextile manufacturing has progressively become distinguished from traditional textile processes. Today it is a highly specialized and technologically sophisticated industry. Since the early 1970s, this evolution has allowed the development of innovative technologies as well as new raw materials specifically adapted for the manufacture of technical textiles for use in civil engineering works.

### *3.1.1 Types of geotextiles*

As one might guess by the etymology of the word 'geotextile', modern manufacturing processes of geotextiles trace their origins to traditional textile manufacturing techniques. Today, we find four main geotextile types, which are defined by the processes used in their manufacture:

- nonwoven
- woven
- knitted
- composite geotextiles

Of this group, nonwovens represent the most commonly used family of geotextiles because of the wide range of functions for which they can be used. Because they are somewhat more limited in their application, woven geotextiles are the second most often used family. The use of knitted geotextiles is much more marginal, and generally limited to niche markets for specific applications that require properties that cannot be economically satisfied by conventional woven or nonwoven geotextiles.

We have also seen new products appear that combine materials and are manufactured using the methods already mentioned, or combined with other geosynthetic products. These new multilayer products are generally grouped together as composite geotextiles.

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#### 3.1.1.1 Nonwoven geotextiles

As mentioned in the previous section, the most widely used geotextile family is, without a doubt, that of nonwoven geotextiles, often referred to as felts. This type of geotextile appears as a web or batt formed with short-staple fibres or directly with filaments. As the name suggests, the manufacturing of these textiles does not require the steps of producing yarn and weaving it. This type of manufacturing process results in products with a random distribution of fibres in the felt body, which allows a certain portion of the fibres to be distributed in the third dimension within the textile web. This three-dimensional distribution is important because it gives thickness and loft to the structure of this product, which is needed for the functions of filtration, drainage and protection. The bonding of the fibres that make up the web or batt is done using various mechanical, heat or even chemical-based processes, depending on the properties required for the finished product. The processes used to produce this type of geotextile allow for the production of heavier and thicker products than those of the other main families of geotextiles. Although many different technologies can be used to manufacture nonwoven textiles, in this chapter we will concentrate on the methods used specifically to manufacture geotextiles.

#### 3.1.1.2 Woven geotextiles

The family of woven geotextiles is that which most closely resembles conventional textiles, because it uses the traditional method of making textiles involving the preparation of yarn, and weaving the yarn together. Weaving can be defined as the action of interlacing two perpendicular yarns or filaments together. Although there are many different weaving methods and patterns, we will always find in these products a series of yarns running longitudinally, and another in the transversal sense of the material. The warp is the series of yarns running lengthwise, and the weft is the series of yarns running in the perpendicular sense across the material. To manufacture woven geotextiles, several types of yarns and filaments (mon-filaments, multifilaments, slit film, fibrillated slit film, etc.) can be woven together depending on the properties required in the finished product. Woven geotextiles have the most compact structure of the three families of geotextiles.

#### 3.1.1.3 Knitted geotextiles

Knitted geotextiles are made using a manufacturing technique that interlaces one or more yarns together in the form of loops. As opposed to woven textiles in which the yarns are perpendicular to one another, knitted textiles are produced by binding symmetrical loops together, which can be oriented in various directions. The loops obtained in this way are referred to as stitches. The symmetrical binding together of stitches gives knitted textiles their main quality, which is the ability to be stretched in one or more directions. What is more, the looped structure allows specific filaments to be integrated into the structure owing to specialized processes, which give very specific functionalities in terms of the textile's extensibility and its directional and mechanical resistance.

#### 3.1.1.4 Composite geotextiles

Composite geotextiles are difficult to categorize because they include two or more product categories. Geocomposites belong to a separate classification within the extended family of geosynthetic textiles. More specifically, as a subfamily of geotextiles, we can group the composite geotextiles into two different groups:

- multilayer geotextiles
- multilayer geosynthetic materials with a geotextile base

Multilayer geotextiles are made up of two or more geotextiles combined to create a new product in which the layers are different but complement each other. The different layers can be of the same geotextile type or of different types: nonwoven, woven or knitted. Combining different geotextile layers gives the product specific properties based on the particular properties of each layer. Among the most popular geocomposites of this family are the nonwoven composite textiles with nonwovens (eg, geotextile with a drainage core, geotextile with a graduated filtration opening) and nonwoven composites with wovens (eg, reinforcement and drainage geotextiles, filtration geotextiles with a calibrated pore size).

Geotextile-based multilayer geosynthetics are multilayer products combining one or more geosynthetic materials, of which at least one is a geotextile. The materials combined within a geotextile can be a geosynthetic from another family or even a different material such as a film of plastic, metal or even a mineral or chemical composite. This type of product is often used in drainage applications. They combine a geotextile drainage grill, miniature perforated drains, drainage sheets or a corrugated plastic core. Geocomposite products with drainage as their main function are often categorized as geodrains. Geosynthetic clay liners and bituminous geomembranes are other good examples of multilayer geosynthetic products, of which one of the main components is a geotextile. Finally, we have seen geocomposites that combine, in the factory, geotextiles with geogrids or geomembranes to make it easier or faster to install a multilayer structure in a worksite which would normally be supplied and installed separately.

### 3.1.2 Raw materials used for geotextile production

As we saw in detail in chapter Geotextile Resins and Additives, various types of raw materials can be used to manufacture the fibres, yarns or filaments that make up geotextiles. Depending on the polymer and the additives used, the type and the dimensions of the fibres, yarns, filaments or slit film, a geotextile can offer specific properties that allow it to accomplish the desired functions. The specific properties required are generally determined by its main function and can depend on where it is to be installed, the chemical and biological composition of the soil, the nature and temperature of the products that come in contact with the geotextile, and the degree of exposure to the sun's UV rays. Finally, the type of geotextile, its manufacturing process, as well as the availability and cost of the raw materials influence the choice of polymers and additives that the manufacturer will use in developing the product.

### 3.1.2.1 Polymers

Polypropylene and polyester are the polymers most commonly used in the manufacture of geotextiles. Polypropylene is chiefly used for its chemical stability and its cost/weight ratio, which gives the geotextile the advantage of being more resistant at a given price than its equivalent made from polyester. With specific gravity of about 0.90 g/cm$^3$, polypropylene is the lightest polymer used for geotextile manufacturing and is lighter than water. On the other hand, polyester offers good chemical resistance and high creep strength, which makes it an option in geotextile manufacturing, especially when the textile requires tensile strength. Polyester has a specific gravity of 1.38 g/cm$^3$, which enables geotextiles made of this polymer to sink when used on the shoreline or on the bed of a body of water. With geotextiles made from short fibres, the manufacturing process allows the blending of different fibres and thus geotextiles to be made from various polymers depending on the specific requirements of the application. The basic resistance of polypropylene and polyester fibres to different agents is defined in Table 3.1.

Polyethylene and polyamides (eg, nylon) are also sometimes used to manufacture geotextiles. Although they are often used to manufacture geomembranes, the lack of supply of polyethylene fibres makes them a rarely used solution in the field of geotextiles. Nylon has less resistance to acids and aging and is therefore less appropriate for use in natural environments. Nylon is often used for knitted socks covering perforated drainage pipes.

For some applications such as erosion control, natural fibre—based geotextiles are used. These products can be used when degradability is required or where environmental requirements are high. You can find more information about this type of product in the following chapter "Geotextiles Made From Natural Fibers."

### 3.1.2.2 Dimensions

The dimension of the fibre, yarn or filament has a direct impact on the mechanical and hydraulic properties of the geotextile. Fibre dimension is expressed according to its diameter, described in deniers or dtex, depending on the measuring system used (American or International System). Thread dimension is generally defined by its yarn density. In the case of nonwoven geotextiles made from short staple fibres, fibre dimension is completed by the length of the cut fibres.

In terms of mechanical resistance, larger fibres tend to offer greater resistance and thus result in a more resistant geotextile. In terms of hydraulic performance, the use of larger yarn and fibres results in a coarser structure with more large pore openings, which tend to allow more fine particles as well as a greater volume of water to pass through the structure.

When the product is being designed, the manufacturer must select the average fibre size and the yarn appropriate to the mechanical and hydraulic requirements, while minimizing the overall weight of the product to obtain the required specifications, while keeping the cost of the geotextile as low as possible. For processes using continuous filaments, the spinnerets used on the extruding equipment determine the

**Table 3.1** **Resistance of polypropylene and polyester to degrading agents**

| | Acid resistance (pH < 7) | Alkali or base resistance (pH > 7) | Hydrocarbon resistance | Solvent resistance | UV resistance | Mould resistance | Heat resistance |
|---|---|---|---|---|---|---|---|
| Polypropylene (PP) | Excellent resistance to most acids, except for significant deterioration when exposed to high temperatures in the presence of acids | Excellent resistance to most alkalis<br>• Considered stable when pH is between 2 and 13 | Not recommended for direct contact with temperatures above 73°F (16°C)<br>Molecular chains break down under prolonged contact | • Low resistance to solvents, especially in temperatures above 140°F (60°C) | Good resistance to UV | Good resistance to mould | Softens at 235–285°F (115–140°C)<br>• Melts at 300°F (150°C)<br>• Not inflammable |
| Polyester (PET) | Good resistance to mineral acids | Good resistance to weak alkalis<br>• Disintegrates in presence of strong alkalis and high temperatures<br>• Very sensitive to sodium hydroxide, for example | Good resistance at 60°F (15°C)<br>Not recommended for direct contact with temperatures above 150°F (66°C) | Insoluble in most solvents except for certain phenols, which can cause swelling of PET | Loss of strength when exposed to UV for long periods of time | Good resistance to mould | Becomes sticky at 440–450°F (225–235°C)<br>• Melts at 480–495°F (250–255°C)<br>• Not inflammable |

production of the fibres used in the geotextile to a fixed dimension for each production lot. However, when mixtures of cut short staple fibres are used, in the case of nonwoven needlepunched geotextiles, for example, the manufacturer can take advantage of using a mix of fibres of different dimensions (denier and length) to achieve the desired properties depending on the availability of the raw materials and the required dimensions.

#### *3.1.2.3 Colour*

The polymer used in manufacturing the geotextiles is often black, to take advantage of the presence of black carbon particles in the polymer that significantly increase UV resistance. However, certain additives can be combined with the natural or white polymer, which can render it just as resistant to UV rays as the equivalent product in black.

Some geotextiles designed for specific uses are offered in colours other than the usual black or white. For example, orange geotextiles are used in applications when one wants to give a danger warning during a future excavation (in case of contaminated soil or buried infrastructures, etc.). Products are also offered in green for applications that will remain visible, to blend in better with the landscape or to indicate that the textile is composed of recycled material.

#### *3.1.2.4 Type of fibres or filaments*

Nonwoven geotextiles use two types of fibres: continuous filaments and short staple fibres. The fibre type is determined by how the fibre is produced, and the manufacturing process of the geotextile determines what sort of fibre will be used. Continuous filament fibres are used in continuous manufacturing processes, in which the fibre is extruded and consolidated in one step, as in the case of spunlaid-type processes. Short staple fibres, on the other hand, are produced packaged and stored before being used in the second stage of manufacturing geotextiles. This type of fibre is used in several different manufacturing processes (carded-needled, airlaid, spunlaced, etc.). Short staple fibres are often manufactured by manufacturers different from those who will transform the fibre into geotextiles. Some manufacturers prefer to do both to increase the economy of scale and reduce production costs, whereas other manufacturers choose to reduce capital investment and specialize in their respective field of expertise, whether it is the production of fibres or the production of geotextiles.

Woven and knitted geotextiles require different types of yarn or filaments: monofilaments, multifilaments, slit film (mono- and multifilament) and fibrillated filaments. Monofilaments are produced in a single step by extruding polymer through spinnerets followed by drawing, processing and rolling it on spools. Multifilament refers to yarn manufactured from several filaments twisted together to form a single thread. Slit-film type filaments are produced by cutting a flat extruded film into strips a few millimetres wide. These strips can be used individually for monofilament products or they can be rolled together to produce multifilament yarns. Finally, these strips can also be treated with a fibrillation process, which creates fine cuts in the strips to produce thinner filaments. This is called fibrillated slit film. Use of fibrillated slit film results in a structure that is more compact than when ordinary slit film is used in the weaving process.

### 3.1.3 Key properties and functions of different types of geotextiles

#### 3.1.3.1 Geotextile properties

For geotextiles to fill a specific role on a construction site, they must be specially designed to accomplish one or more specific functions complementary to the natural materials present in the soil. To satisfy these functions, the geotextile must therefore offer the right combination of specific physical properties. These physical properties are generally satisfied by the appropriate combination of raw materials, by the manufacturing process and by adjusting the production parameters. It is therefore largely the result of the process of transforming polymer into a textile by which the product acquires the specific properties that make it a geotextile adapted to the use it will have on the worksite.

Geotextiles offer various properties that we can categorize into three main families; the physical properties refer to the dimensional characteristics of the product. Mechanical properties refer to the behaviour of the geotextile when it is subjected to mechanical constraints. Hydraulic properties describe the behaviour of the geotextile in the presence of liquids or gases. The key properties of geotextiles are defined in Table 3.2.

#### 3.1.3.2 Geotextile functions

Geotextiles can offer a limited number of well-defined properties in their applications. The functions generally attributed to geosynthetic products are separation, filtration, drainage, reinforcement, protection and, in some cases, a liquid barrier. These key functions can be defined as follows:

- Filtration: Geotextiles are used to retain fine soil particles in which they are in contact. This function prevents fine particles from being leached and draining elements in surrounding areas from becoming clogged. This is probably the most common function in geotextiles and they reason for their creation in the mid-1960s.
- Separation: Geotextiles are used to retain particles of varying granulometries in two distinct layers and to prevent the two adjacent layers from mixing. Wherever two soils that are in contact have incompatible granulometries, a natural or synthetic separator is necessary to ensure the long-term performance of the structure. Geotextiles are thus a synthetic solution to this challenge.
- Drainage: Geotextiles are used as a passive element to transport liquids or gas in their own bed. The drainage function is sometimes done by the geotextile alone, but more often it is combined with other elements (drainage core, perforated pipes, etc.). This combination is referred to as drainage geocomposites.
- Reinforcement: Geotextiles are used to increase the load-bearing capacity of soft soils or to absorb significant frictional forces at the interface of soil and a smooth surface where there is a risk of sliding. Reinforcement is an application used often in the field of road engineering.

**Table 3.2 Main properties of geotextiles**

| | Property | Metric units | Imperial units |
|---|---|---|---|
| Physical properties | Weight | Grams/square metre ($g/m^2$) | Ounces/square yard ($oz/yd^2$) |
| | Thickness | Millimetres (mm) | Mils (mil) |
| | Dimensions (width, length) | Metres (m) | Feet (ft) |
| Mechanical properties | Tensile strength | Newtons (N) | Pounds (lb) |
| | Tear strength | Newtons (N) | Pounds (lb) |
| | Compression resistance | Percentage (%) | Percentage (%) |
| | Puncture resistance | Newtons (N) | Pounds (lb) |
| | Elongation | Percentage (%) | Percentage (%) |
| Hydraulic properties | Permittivity | Per second ($s^{-1}$) | Per second ($s^{-1}$) |
| | Water flow | Litres/minute/square metre ($L/min/m^2$) | Gallons/minute/square foot ($gpm/ft^2$) |
| | Pore opening size | Millimetres (mm) | US Standard Sieve (Sieve) |

The use of reinforcing geotextiles can increase the module of a soft soil and satisfy load-bearing requirements in the construction of a road or road-building project (bridge, overpass, etc.). This application is also used in the field of environmental engineering to increase the frictional force of a smooth geomembrane.

- Protection: Geotextiles are used to protect geomembranes, concrete slabs or any other relatively fragile element requiring special attention. Protection is an application that is chiefly used in environmental engineering, in association with the use of a geomembrane. In some other cases, we find an application in civil engineering, notably in tunnel construction.
- Liquid barrier: Geotextiles to which a treatment has been applied or has been joined with another element such as bitumen or clay is used to seal the earth partially or completely to retain and prevent the passage of liquids or gas that is in contact with the geosynthetic material.

The geotextile's properties are often closely connected to its function. One would even be tempted to associate some of these properties or even certain geotextiles with these particular functions. For example, when geotextiles were first used in the 1960s, the products that were intended to separate and filter soils were commonly called 'filter' fabrics. People still speak of a thick geotextile to describe its puncture resistance, or a closed geotextile to describe its high capacity for retaining fines. Table 3.3 shows the relationship between a geotextile's properties and the application for which it is used.

**Table 3.3** **Relation between functions and properties of geotextiles**

| | Physical properties | | | Mechanical properties | | | | | Hydraulic properties | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | Weight | Thickness | Dimensions | Puncture | Tensile strength | Compression | Tearing | Elongation | Permeability | Flow capacity | Pore openings |
| Filtration | | X | | | | | | | X | | X |
| Separation | | X | | | | | | | X | | X |
| Drainage | | X | | | | X | | | X | X | |
| Reinforcement | | | | | X | | X | X | | | |
| Protection | X | X | | X | X | | X | | | | |
| Liquid barrier | | | | | | | | | X | X | X |

To interpret the information in Table 3.3 properly, it is necessary to understand that some properties are linked with each other and one must add two or more properties to achieve the required function. As an example, flow capacity is linked to the thickness and permeability of the geotextile, and is also influenced by the compression resistance.

#### 3.1.3.3 Geotextile manufacturing processes and their effects on properties and functions

In the previous section, we saw that the properties of different products can be interrelated and that there is a relationship between these properties and the functions performed by the geotextile. In this section, we will explain that a geotextile's properties are highly influenced by the manufacturing processes used to make them. For example, a woven geotextile will have a lower elongation than a nonwoven geotextile for an equivalent tensile strength, and a nonwoven needlepunched geotextile will have smaller pore opening size than monofilament or slit film woven geotextiles.

The impact of the manufacturing process on the geotextile's mechanical properties is easily demonstrated with a standard stress−strain curve. Fig. 3.1 shows that the different types of geotextiles have a greatly differing behaviour under strain.

By understanding that the properties of a geotextile have an influence the functions they provide, one can imagine that certain types of geotextiles have a predisposition to fill specific functions. Table 3.4 shows the main families of geotextiles compared with their performance in satisfying their principal functions.

The specific structure of each type of nonwoven geotextile, which is a result of the manufacturing process, has a direct impact on the capacity of the geotextile to perform its function in the soil. Table 3.5 shows in greater detail the main relationships of the manufacturing process, the structure of the geotextile and its performance in the functions for which it is adapted.

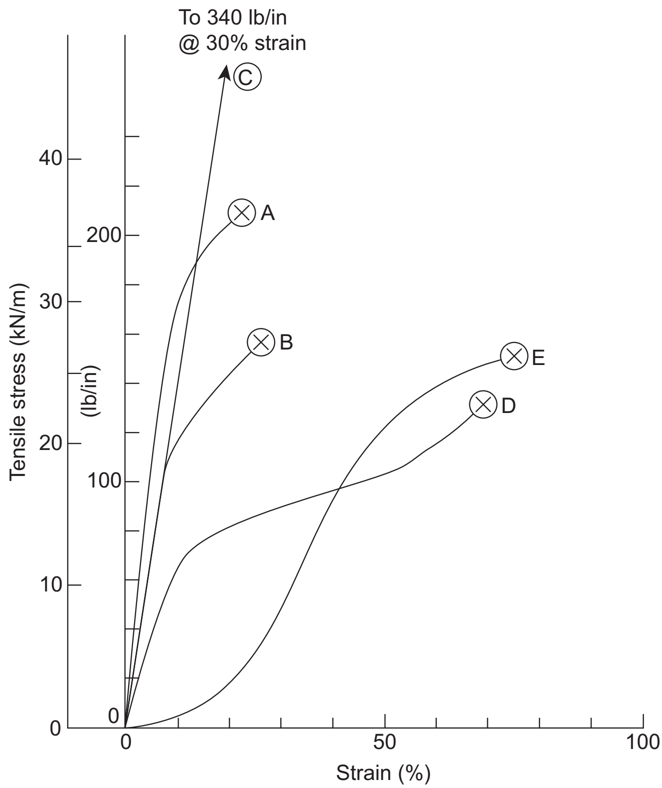
## 3.2 Geotextile manufacturing processes

### 3.2.1 Global manufacturing process

The manufacturing processes for geotextiles are conventional processes that can be described as the transformation of a raw material into a finished product. Like any other modern transformation process, the stages of quality control, conditioning, inspection and secondary transformation can be added all along the production chain. The following sections present the main generic stages in the process of manufacturing modern geotextiles.

#### 3.2.1.1 Raw material reception, control and processing

Geotextiles are made from polymers that are available in the form of pellets, cut fibres, yarns, filaments or strips. These raw materials must be received at the production site and inspected to ensure their conformity with the specifications of their purchase order. For each raw material, the specific and well-defined parameters must be verified and




Legend

| Curve | Manufacturing type | Mass/unit area (oz/yd$^2$) | Thickness (mils) |
|---|---|---|---|
| A | Woven, monofilament | 6 | 15 |
| B | Woven, slit film | 5 | 10 |
| C | Woven, multifilament | 8 | 28 |
| D | Nonwoven, heat bonded | 4 | 13 |
| E | Nonwoven, needle punched | 6 | 25 |

**Figure 3.1** Typical geotextile stress−strain curves.
Source: Koerner, R.M., 2012. Designing With Geosynthetics, sixth ed., Xlibris Publ. Co, USA.

controlled, both to ensure the respect of target values and for variations in quality between different lots received and even within a given production lot.

For natural raw materials as well as synthetics, a conditioning time is generally required to stabilize temperature and humidity, because these two parameters have an important impact on the productivity of the manufacturing process as well as the quality and performance of the finished products. The raw materials must therefore be stored under shelter and under controlled conditions. The moisture level in the

**Table 3.4 Performance of geotextile families to achieve functions**

| | Filtration | Separation | Drainage | Reinforcement | Protection | Liquid barrier |
|---|---|---|---|---|---|---|
| Nonwoven | XX | XX | XX | X | XXX | – |
| Woven | X | XX | – | XXX | – | – |
| Knitted | XXX | – | – | X | – | – |
| Composites | Variable depending on design of composite | | | | | |

–, Not applicable; X, adapted to certain applications; XX, adapted to most applications; XXX, ideal solution.

storage and manufacturing areas must be maintained at an adequate level, and the specific stages in the transformation process must be planned to adjust the temperature and moisture levels of the raw materials during the transformation process. For example, it is important to dry a polymer mix before it is extruded and to humidify the short staple fibres before they are carded to facilitate their transformation and avoid imperfections in the finished product. Each process and each manufacturer has its necessary means for controlling temperature and moisture, which are related to the process, equipment used and the manufacturer's own experience.

Besides the raw materials that are transformed, many other elements come to the factories, whether for packaging (tubes, bags, labels, etc.) or for the product transformation (needles, lubricants, etc.). Each of these elements should have its own complete specification sheets that allow the manufacturer to ensure the quality of the materials delivered by suppliers. These specification sheets should be part of the contract that binds the supplier with the manufacturer, to ensure the quality of the manufactured products, respect delays and avoid unforeseen problems (costs and delays) associated with the use of nonstandard raw materials.

#### *3.2.1.2 Geotextile manufacturing*

At the heart of the geotextile manufacturing process, one finds the carding-needlepunch operations and spunbonding (for nonwoven geotextiles), weaving (for woven geotextiles) and knitting (for knitted geotextiles). This stage takes the raw materials from the state of pellets, fibres, filaments or slit film to the state of a web, batt or fabric. A detailed technical explanation of these processes is presented later in Section 3.2.2.

#### *3.2.1.3 Geotextile finishing*

Once the geotextile is consolidated in the form of a fabric with its specific physical, mechanical and hydraulic qualities, it is possible to apply finishing treatments to modify its final properties and performance. Some of the most common finishing treatments are often integrated in-line with the manufacturing process to avoid additional costs related to the double manipulation of the product and additional steps

**Table 3.5** **Relationship between manufacturing process and functions of geotextiles**

| | | Woven | | |
|---|---|---|---|---|
| | **Nonwoven** | **Slit film** | **Monofilaments** | **Knitted** |
| Filtration | Needlepunch technique and use of mix of fibres of different dimensions makes it possible to control pore size openings with great precision. Openings can be very small or large, thus giving nonwoven geotextiles an advantage over other products. | | Openings are often very large but very even. The product can thus lend itself to precise applications such a nonclogging filter. | The evenness of knitted geotextile makes it possible to control openings perfectly, as well as the ability to obtain very fine openings that are ideal for filtration of sandy or silty soils. The ability to stretch and the round form that can be obtained by certain knitting procedures make this product an economical solution for use around perforated drainage pipes. |
| Separation | The open, lofty structure of nonwoven needlepunched geotextiles gives them the capacity to manage water well, as well as fine particles in soil, while providing efficient mechanical separation owing to resistance to mechanical forces, which can be strong. | The high elongation modulus of woven slit film geotextiles lends itself to combining two functions that often coexist in road engineering applications: separation and reinforcement. | | |

*Continued*

**Table 3.5** **Continued**

| | | Woven | | |
|---|---|---|---|---|
| | **Nonwoven** | **Slit film** | **Monofilaments** | **Knitted** |
| Drainage | Needlepunch makes it possible to obtain an open and lofty structure, offering thickness and permeability needed for drainage functions.<br>Nonwoven needlepunched geotextiles are often used combined with other fibres and materials to increase drainage capacity. | | | |
| Reinforcement | | Among most often used reinforcement solutions, owing to their low elongation and high tensile strength, relative to their thickness and weight. This good mechanical performance combined with their light weight makes them an economical solution for this application. | Conventional woven monofilament geotextiles are sometimes used for light reinforcement applications and are generally combined with nonwoven geotextiles.<br>Woven high-tenacity monofilament geotextiles have been developed and are well-suited for reinforcement functions owing to their excellent tensile strength. | They are used for speciality applications where extreme reinforcement is required.<br>They offer significantly low elongation and high tensile strength versus thickness/weight. It is possible to create multidimensional structures and integrate other elements for directional reinforcement. |

| | | | | |
|---|---|---|---|---|
| Protection | Needlepunch method allows tighter binding and entangling of the fibres, offering a cohesive, puncture-resistant structure. This process allows the production of heavy weights combined with important thickness, which in turn offers very good puncture resistance. | | | |
| Liquid barrier | The open structure of nonwoven geotextiles allows them to be soaked with bitumen or combined with clay particles that enter open spaces within the structure of the geotextile to prohibit the passage of liquids. | | | |

in the production. The finishing stages done in the production line render the process more complex, however, and increase the risk of product loss owing to nonstandard quality or performance of the process. For this reason, it is important to evaluate the typical size of production lots before choosing the finishing processes that are to be used either in the production line or as an off-line secondary process. Table 3.6 presents several common finishing processes that can be applied to geotextiles.

### 3.2.1.4 Geotextile inspection, slitting, winding and packaging

The production process is completed by inspection, cutting, winding and packaging. Depending on the technology used by the manufacturer, these steps may be more or less automated. For example, in the conventional textile industry, it is not rare to see off-line inspection tables. However, in modern continuous production methods, which are much more rapid, these manual inspection procedures have been replaced with digital cameras or metal detection induction loops that make it possible to ensure product quality even at very great speeds. Inspection generally aims to verify product consistency, the absence of apparent holes or flaws, as well as the potential presence of undesirable contaminants, such as bits of metal or needles.

Products are generally manufactured according to the nominal widths of the manufacturer's production line. These widths are often standardized within the industry depending on the region in the global market. When the applications require dimensions that differ from those available currently on the market, the products can be manufactured to specified widths or be either cut or sewn in the course of a later transformation.

Packaging of geotextiles is also standardized in most regions of the world, in consideration of the hostile outside environment that the products must face before being installed in their final application on worksites. Protection against environmental factors such as rain, contamination and the UV rays of the sun must be taken into consideration in selecting appropriate packaging for geotextiles. In addition, human intervention such as storage, handling, loading and unloading increase the level of protection required for packaging.

### 3.2.1.5 Quality control during production

To ensure specifications are met, the manufacturer must put into place a quality control programme and ensure constant product quality oversight with respect to the quality control plan. Independent organizations or associations such as ISO (ISO-9000), GRI (GAI-LAP), etc. often supervise control programmes. These programmes generally oversee the methods of control, the certification process, calibration of measuring instruments and a system for management of nonconforming products.

Manufacturers who care about the quality of their products must put into place a quality control system and ensure its effectiveness through the periodic use of audits and internal controls. Companies using high-volume production methods often choose to put into place methods of statistical control that allow them to react proactively in preventing nonconforming products at the source of the production. Specialized

Table 3.6 **Common finishing processes for geotextile manufacturing**

| Process | Process description | Impact on product | Equipment used |
|---|---|---|---|
| Thermo-fixing | Heat material to bring fibres to limit of their melting point so that fibres will bond together permanently | • Stabilization of dimensional properties of product<br>• Increase tensile strength | Infrared elements<br>Conventional gas oven |
| Calendering | Compress geotextile under high pressure and high temperature using heated metal rollers | • Temperature stabilization of product<br>• Calibration of hydraulic properties by adjusting density of material<br>• Reducing thickness of product | Calendaring |
| Coating and impregnation | Addition of resin or chemical composition to surface or into internal structure of material | • Modifying surface and internal properties of geotextile<br>• Increasing the rigidity of the product<br>• Modifying hydraulic properties of textile to render it water-proof or water-resistant | Resin bath<br>Padder<br>Knife coating<br>Spray coating |
| Bonding | Application of adhesive, generally at a high temperature, between two layers of material and apply pressure to bond two layers together | • Associating two layers of geotextiles or geosynthetics together to obtain hybrid properties, which take advantage of specific functions of both types of geosynthetic textiles | Laminator<br>Singing machine<br>Powder-coating machine |
| Sewing and fusion | Join two geotextiles together using yarn by fusing together part of the material | • Joining two strips of geotextiles side by side to increase total size of product<br>• Joining two layers of geotextiles or geosynthetics together to obtain hybrid properties and benefit from specific properties of different types of geosynthetics | Sewing machine<br>Ultrasonic welder<br>Quilter |
| Slitting | Dividing geotextile web into two or more strips | • Dividing geotextile web to adjust its width to correspond with width required for its use | Circular saw<br>Score slitter<br>Knife |

equipment can also be installed at the production line stage to follow the properties of the manufactured products continuously (weight, thickness, porosity, colour and defects, etc.). This type of equipment makes it possible to substantially reduce losses generated by nonconforming products.

During specific projects, it is common to see quality control performed on the worksite on lots sent by the manufacturer. This type of control is generally carried out by a third party mandated by the client or an engineer mandated by the client. In a case where nonconforming materials are found on the worksite, the plans and specifications usually specify the terms of replacement for the material, and related penalties. This sort of event is often costly for the client and the manufacturer, so it is in the interest of geotextile producers to ensure the quality of their products and ensure conformity in the factory before they are sent.

#### *3.2.1.6 Product and yield recycling*

As for every manufacturing process, geotextile manufacturing has its share of challenges and problems, which cause the manufacturer to experience certain losses. We can identify two sorts of losses: those that are intrinsic and those that are extrinsic to the process. Intrinsic losses are those that come from the manufacturing process in itself and are difficult to reduce without modifying the process. Extrinsic losses are losses happening sporadically during production and are caused by various external factors to which one can react to reduce their occurrence. Here are some examples of the most common sources of these losses:

- Intrinsic
  - Start of production
  - Transition between different grades of a product
  - Uneven borders of the product that need to be cut
  - Periodic cleaning and maintenance of equipment
- Extrinsic
  - Problems with raw materials
  - Mechanical failures
  - Various problems involving adjustment of work methods
  - Loss of control of work methods
  - Workplace accidents
  - Human error

In the interest of profitability and environmental protection, manufacturers have developed methods of recycling waste generated by some of the previous causes. Whether it means reshaping, grinding or shredding, there are a multitude of processes for recycling waste. The by-products generated by these processes can be reintegrated into raw materials or be used to make special products from recycled materials.

In some cases, geotextile-manufacturing processes can benefit from adding recycled raw materials coming from outside the manufacturing process. In this context, we are referring to postproduction or postconsumer recycled products. Postproduction products are products that achieved the stage of being finished or were in the process of being finished without reaching the commercial distribution stage. Postconsumer products, on the other hand, were sold and used by consumers for the functions for which they were intended before being recycled.

Considering that these recycled materials have properties different from new raw materials, it is important to limit the use of this type of material to applications that allow it, and to limit its proportion to ensure that this material does not have a negative impact on the final performance of the product. The use of recycled material is often controlled by national and international industry standards.

#### 3.2.1.7 Postproduction transformation of geotextiles

For some applications, manufactured geotextiles will be stored in a final state before being transformed into another product. In this situation, we speak of the secondary transformation of the geotextile. This type of transformation is often used to manufacture geocomposites made from geotextiles. The geotextile can therefore be considered a raw material in the manufacturing process of the geocomposite. These complementary production stages can be considered manufacturing processes in their own right, in conformity with the stages already described.

### 3.2.2 Nonwoven geotextile manufacturing processes

Nonwoven geotextiles are geotextiles that are manufactured without the use of a weaving process. The fibres are bonded together directly using a mechanical, thermal or chemical bonding process. A combination of different bonding methods is also possible. For example, a product is often needled and thermofixed. As shown in Fig. 3.2, one can define two main families of nonwoven geotextiles: short staple fibre—based nonwoven and continuous filament—based nonwoven.

#### 3.2.2.1 Nonwoven made from short staple fibres

Short staple fibre—based nonwoven geotextiles are obtained by a process in two distinct stages. In the first stage, the filament is extruded, cut and baled. In the second stage, these bales are opened, blended and transformed into geotextiles by a mechanical, heat or chemical bonding process. This type of process makes it possible to obtain a large spectrum of geotextile products with a wide variety of weights (from light to very heavy) while giving the product a generally lofty internal structure.

In the first stage of this process, the fibre blend is prepared from the bales received from the extrusion line or from a fibre supplier to produce a blend that is homogeneous and follows the product's recipe. At this stage, one can blend fibres with different properties (polymers, colours and dimensions) to achieve the properties required for the finished product. The main operations involved in this stage of the manufacturing process are thus:

- Preparation of the fibre blend:
  - Bale opening
  - Fibre blending
  - Blend opening
  - Process feeding

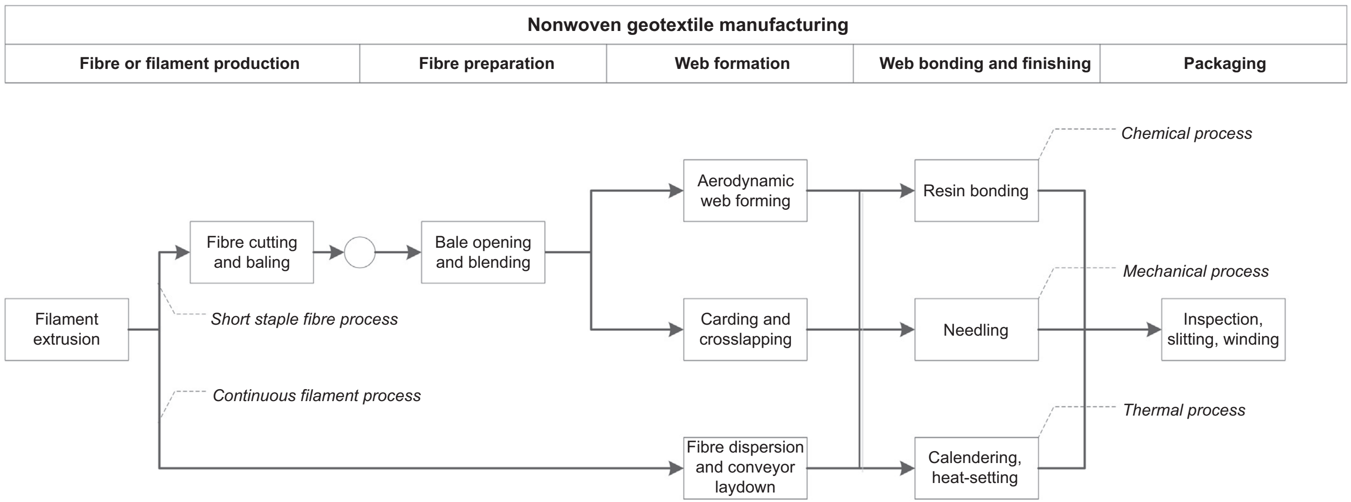



**Figure 3.2** Nonwoven geotextile manufacturing process flowchart.

Bales are generally opened directly on the production line and placed in weighing boxes equipped with an inclined apron covered with spikes and load cells to measure and unload the appropriate quantity of each of the fibre bales onto an in-feed conveyor. This conveyor will then direct the fibres to the first stage of the opening process performed by the carding willow. The carding willow uses a group of rollers equipped with spikes that turn at a high speed to begin the first stage of opening. After this initial stage, a fine opening can be performed by opening equipment adapted to the type and size of the fibres used in the blend. The fine opening equipment uses more or less the same principle as the carding willow, except that the spikes on the rollers are replaced by metallic wire clothing. Finally, after these initial stages, the homogeneous blend is ready to be transformed and is directed to the vibration chute feed. The movement of the fibre blending from one stage to another is generally done aerodynamically with the help of a specially adapted blower that blows the fibres through metal ducts. Some large-volume producers employing large quantities of uniform fibre blends use centralized blending chambers for the production factory which can be used to feed several production lines.

The second stage in the process involves preparing the geotextile batt to provide it with properties required to make it into a geotextile. At this stage, the fibre blend is worked to distribute the fibres according to the desired alignment, which can be oriented or random, depending on the process used. The main operations in this stage of production are:

- Preparing the batt
  - Carding or the aerodynamic formation of the batt
  - Crosslapping

Carding is the most commonly used process for producing short staple fibre—based nonwoven geotextiles. However, for some speciality products, and more specifically with the arrival of natural fibre—based products, an aerodynamic process can be used in certain cases. The carding operation consists of passing the fibre blend between a series of rollers covered with metallic wire clothing whose role is to comb and align the fibres. At the end of this process, the fibres are aligned longitudinally in relation to the card. The web that leaves the carding operation is very light and has no mechanical cohesion. For this web to achieve the desired weight, it is necessary to pile several web layers one atop the other. This phase is carried out with a machine called a crosslapper. When this multilayer web leaves the crosslapper, it is deposited on the feeding bed and is directed to the next stage, that of bonding.

The third stage in this process consists of bonding the web into a geotextile possessing the physical and mechanical characteristics that approach those of the finished product. The bonding process can be done using mechanical, thermal or chemical means. These are the principle operations of this stage of the process:

- Bonding of the web:
  - Needling
  - Calendering
  - Resin bonding

Needling is the process most often used to produce nonwoven geotextiles made from short staple fibres. This process consists of passing the web of fibres spread in the needlepunching machine between two plates of metal with holes that allow the needles, which are equipped with small barbs, to pass repeatedly through the material. The back-and-forth movement of the needles is generated by the rotation of an eccentric wheel connected to plates on which thousands of needles are fixed. The barbs at the end of these needles act to interweave the fibres to create a random structure in which the fibres are tangled together. Needling allows the creation of a felt with a certain level of cohesion depending on the intensity of the needling. The needling intensity is one function of the process parameters. The most important parameters are the number of strokes per minute, the depth of penetration, the type of needles used and the number of needles per linear metre mounted on the needle boards. The needling phase is done successively in a number of stages in independent machines installed sequentially on the production line. The first needling step of needling is generally referred to as preneedling. Needling is often performed alternatively on both faces of the geotextile to give homogeneous properties to both sides of the product. Figs 3.3 and 3.4 demonstrate the needling process and the needles that are used in this process.

The process of heat bonding using hot calendering is sometimes used in the production of short staple fibre geotextiles. However, this method is more often used for continuous filament—based geotextiles. This process will be explained in detail in the next section covering the continuous filament process.

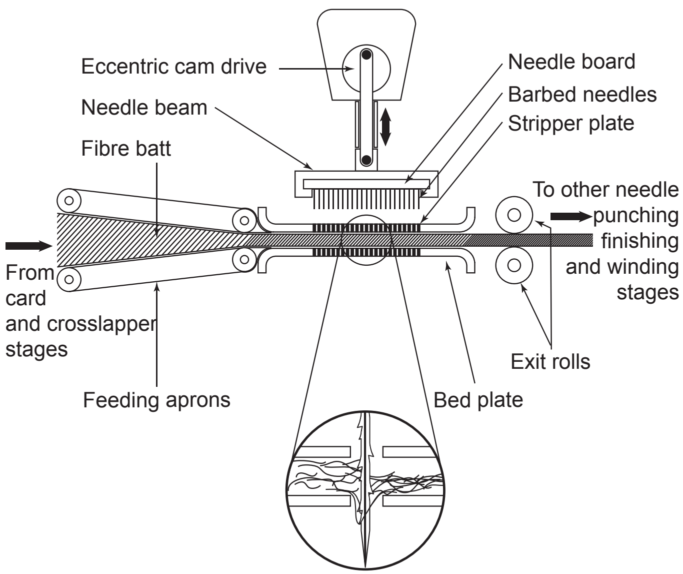



**Figure 3.3** Needlepunching process diagram.
Source: Texel Inc.

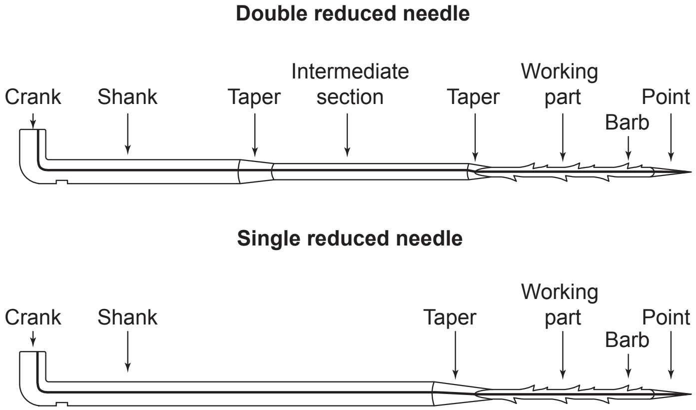



**Figure 3.4** Needles used for needlepunching process.
Source: Groz Beckert, Felting and Structuring Needles Information Guide.

Although it is rare in the conventional geotextile industry, chemical-based bonding processes are particularly interesting for geotextile products with a natural fibre base or for speciality products with characteristics such as biodegradability. This process requires chemical resins to be added to the textile web followed by a drying and curing stage, which serve to bond the fibres together. Three different methods, shown in Fig. 3.5, are most commonly used to apply resins to create chemical bonds to consolidate the textiles: saturation, spraying and rotogravure printing.

After bonding of the geotextile using mechanical means, some thermal or chemical processes, as shown in Section 3.2.1, can be applied to give the product its final physical, mechanical and hydraulic properties. Once the product has attained its final characteristics, it will be inspected, cut and packaged. These procedures can be more or less automated, as was explained in the previous section.

### 3.2.2.2 Nonwoven geotextiles made from continuous filament

Nonwoven geotextiles made from continuous filament are obtained from a one-step process, which transforms polymer pellets into a geotextile with its final characteristics. This is an economical process for light-weight and medium-weight geotextiles because it allows very high-volume, one-step production.

The first step in this process involves the creation of a filament from the polymer pellets. This step is identical to that used to produce the filament used for the production of short staple fibres. The difference is that the filament will not be crimped, cut or baled. Here are the main operations in this process of making the filament:

- Production of the filament:
  - Extrusion
  - Cooling and filtration
  - Filament spinning
  - Drawing

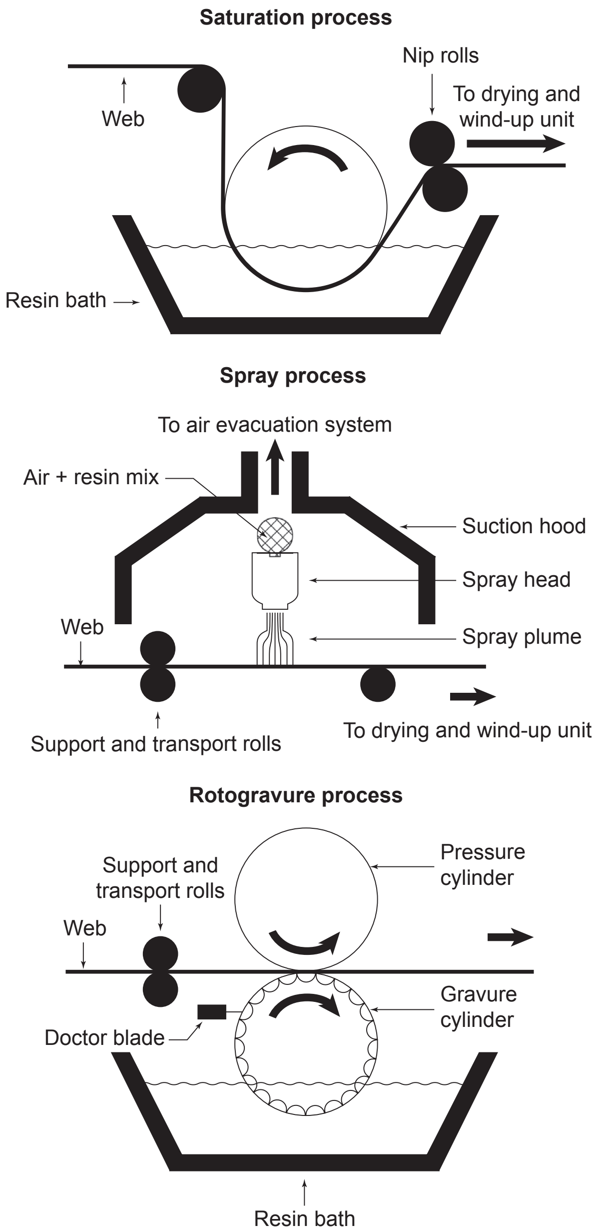



**Figure 3.5** Chemical bonding processes diagrams.

Selected pellets are sent from silos or bulk bags by aerodynamic means into the extruder's hopper. These pellets are then fed to the extruder screw, where additives and colouring agents can be added with the help of a dosing pump. The pellets enter the extruder's feed chamber and are then transported using the mechanical action of a continuous screw. The specific design of this screw pushes the pellets towards the exit, where they will melt under the combined action of friction and pressure. The melted polymer is then cooled and filtered before being pushed by a pump through the spinneret installed at the top of the spinneret beam. The dimension and form of the holes pierced in the spinneret determine the diameter and form of the fibre. Once the filaments leave the spinneret, they are stretched and cooled by air currents, according to established parameters regarding the polymers used and the physicomechanical properties required for the filament. The drawing stage allows for modification of the orientation of the molecular chains in the polymer to procure the mechanical strength required of the filament. The drawing is performed using mechanical or pneumatic techniques specific to each manufacturer of production equipment.

The second step of this process consists of preparing the filament web for the following bonding stages. For the spunbonded production process used in making geotextiles, the filaments are placed on a feed apron situated under the spinneret beams. Here we explain the preparation of the web.

- Preparation of the web:
  - Depositing the filaments on the feed apron

The filaments leave the spinneret beam in aligned bunches under high-pressure air. Electrostatic, aerodynamic and mechanical systems are used to ensure the random distribution of the filaments as they are projected onto the apron. The apron is generally perforated and equipped with a powerful vacuum system so the filaments will be held in place perfectly with a random and homogeneous distribution. By moving the filament-spreading nozzles from side to side as the apron advances, it is possible to obtain a zigzag pattern similar to that created with the spreader in the crosslapper in the carding/crosslapping process.

The third part of this process consists of bonding the web into a geotextile with physical and mechanical characteristics that resemble those of the finished product. The bonding process can be done using mechanical or thermal methods. These are the principle operations of this stage:

- Bonding of the web:
  - Calendering
  - Needling

In the case of nonwoven geotextiles made from continuous filaments, a heat process using calendering is most often used. The filament web spread on the feed apron is directed to a calendar where it will be compressed at a high temperature by two heated metal rollers. The heat and pressure cause the filaments to fuse together where they touch; in this way, they form a cohesive filament structure. Depending on the product required, the calendar can be smooth or have a surface embossing pattern which

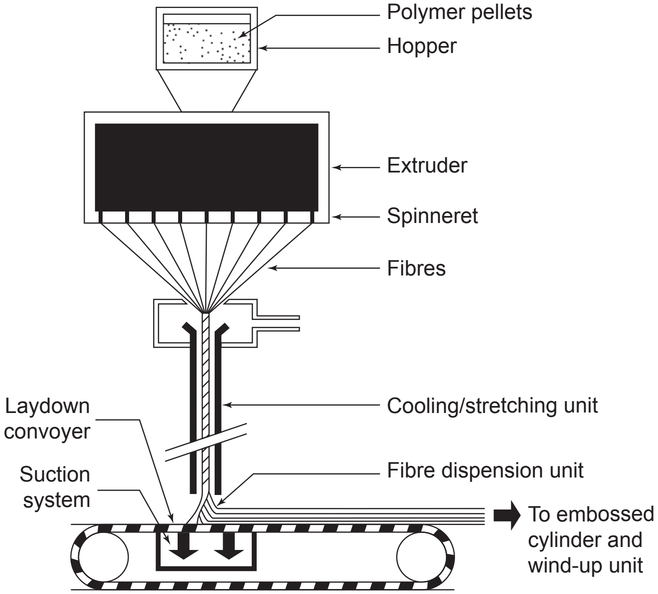



**Figure 3.6** Spunbonding process diagram.
Source: Groz Beckert, Felting and Structuring Needles Information Guide.

provides specific points for fixing fibres together. Fig. 3.6 shows a summary of the classic spunbonding process.

Mechanical bonding performed by needling, as shown in the last section, can also be used to produce nonwoven geotextiles made from continuous filaments. However, this bonding method is slower than the heat method, which limits production volume.

Finally, after the geotextile's bonding, it is directed to the inspection, cutting and packaging stages. These stages, as mentioned before, can be automated. The product will then be stored until it is shipped to the client.

### *3.2.3 Woven geotextiles manufacturing processes*

As we described in the introduction to this section, weaving consists of intertwining two yarns at right angles to create a fabric. Woven fabrics can be made from many different sorts of yarns or filaments. The following list shows the types of yarns or filaments generally used to manufacture geotextiles:

- Spun yarn
- Continuous filament (monofilament) yarn
- Continuous filament (multifilament) yarn
- Slit film yarn
- Fibrillated slit film yarn

Fig. 3.7 shows the different processes and options to produce woven geotextiles.

Woven geotextiles can generally be categorized by the type of yarns or filaments used in their manufacture. For example, we speak of slit film–based geotextiles or geotextiles woven using monofilaments. Some recent products used for special applications can combine different sorts of yarns or filaments together to take advantage of the qualities of each of these technologies.

Although spun yarns are used most commonly in conventional textile industries, their use is more marginal in geotextile manufacturing. This type of yarn is made from short staple fibres that have passed through preparation treatments (carding, combing, stretching and roving) which allow them to be twisted together to produce a homogeneous and continuous thread. The twisting of the yarn can be done either in a clockwise or counterclockwise manner. As such, we speak of yarn having either an S or a Z twist. The twisting stage helps to improve the performance of the yarn; the more the yarn has been twisted, the greater will be its mechanical resistance.

Continuous filaments are produced by the extrusion of polymer pellets in the form of one or more continuous strands, which generally are round in cross-section. Some filaments have other forms in cross-section, depending on the form of the spinnerets used for their production (eg, oval, trilobal, hollow core). The shape of the strand's cross-section lends specific properties to the different filaments. It is possible to use extruded filaments directly, individually. In this case, they are known as monofilaments. Several filaments can also be joined together by a twisting process to create what we call multifilaments. Woven geotextiles made from filaments are generally used for high-tenacity reinforcement applications and when filtration must be controlled with precision.

Slit film yarn is made from an extruded polymer film that is cut into thin bands before being wound in the form of creels, which will be used later in the weaving stage. As mentioned, slit film can be a single strand or fibrillated depending on the properties required for the finished geotextile. Geotextiles made from slit film are generally used for separation and reinforcement applications in soils with a low bearing capacity, where filtration characteristics are of little importance.

After the yarns, filaments or slit film tapes have been spun, extruded or cut, they are wound on creels or cones. Then, some of these yarns, filaments or slit film tapes will be wound on a warp beam to be unrolled lengthwise to the fabric. This stage is known as warping. The warp yarns are generally sized with a protective glaze to protect them from abrasion that takes place during the weaving process. The yarns, filaments or slit film tapes are now ready to be mounted on a weaving loom in preparation for the manufacture of a textile. The warp threads will be sent through the various security guide elements and inserted into the reed and the heddles of the machine before they are knotted with the yarns already mounted on the machine.

The weaving process is generally the same regardless of whether yarns, filaments or split film tapes are being used. The longitudinal threads are called the warp. They are intertwined with the transversal threads, known as the weft. The weft threads are

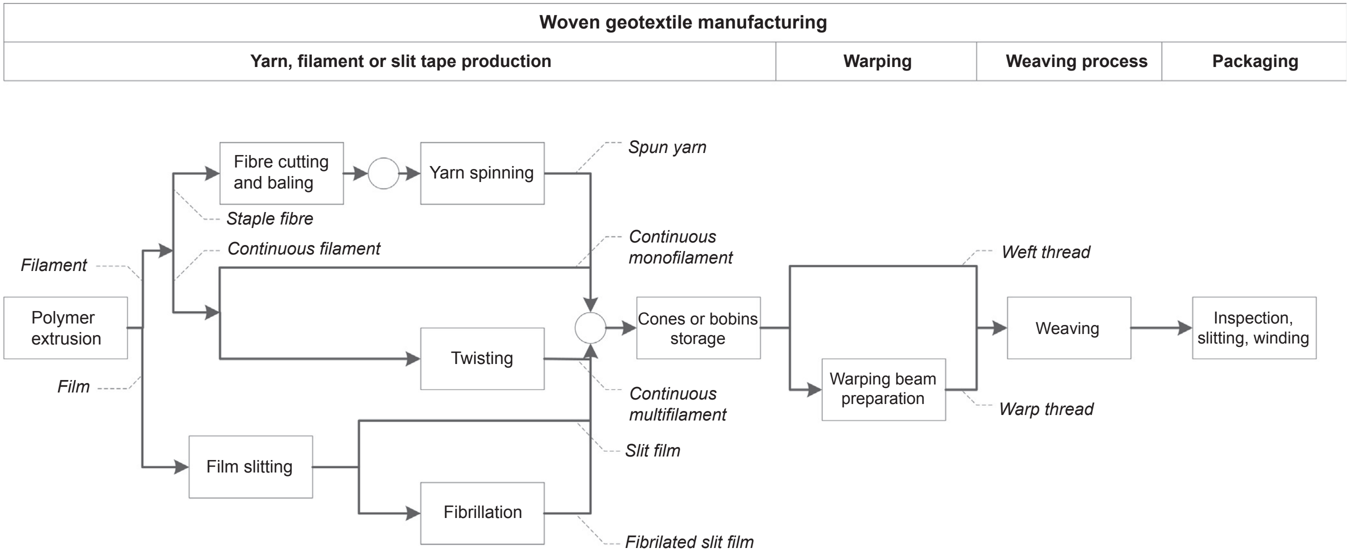



**Figure 3.7** Woven geotextile manufacturing process flowchart.

inserted sequentially from one side of the weaving loom to the other, between the threads of the warp. This insertion of the spindle is done using a mechanical element that varies depending on the weaving technique being used: stick shuttle, flying shuttle, air jet or water jet.

To form the interweaving design known as the weaving pattern, some of the warp threads are raised and others are lowered in the loom. Two types of simple patterns are often used: plain weave and twill weave. The pattern with a checkerboard pattern where the weft threads pass alternately over and under the adjacent warp threads is known as plain weave. The pattern in which a weft thread passes under a warp thread and then over the three next warp threads is called twill weave. Twill pattern has fewer intersections between the threads, which permits a tighter weave than plain weave. The pore opening size for filtration in a woven geotextile is influenced by the type of pattern chosen as well as the size of the threads used and some of the mechanical characteristics of the weaving equipment (notably the reed, which determines the degree of compaction of the warp and weft threads).

As illustrated on Fig. 3.8, a weaving loom is generally composed of the following parts:

- The weaver's beam is the creel that holds the warp threads ready to be woven.
- The heddles are the mobile elements of the loom that raise and lower the warp threads to create a tunnel for the weft threads to pass through.
- The reed separates the warp threads and makes it possible to push together the weft threads after each pass of the shuttle.
- The shuttle is the part of the weaving loom that holds the weft yarn and is alternately sent from one side of the loom to the other to transport the transversal yarns of the weaving pattern.
- The cloth beam is used to wind the woven geotextile as it is produced on the loom.

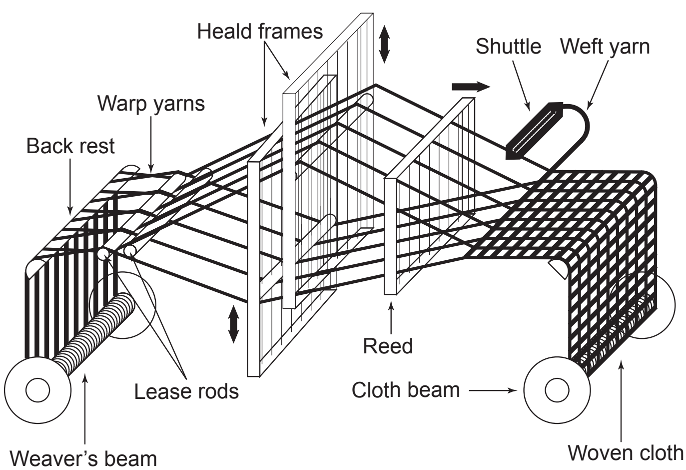



**Figure 3.8** Weaving loom diagram.

The yarn is therefore unrolled from the weaver's beam and directed to the moving parts of the loom. The weaving process is fairly simple and involves three distinct stages:

- Shedding: the separation warp threads in two layers to form a tunnel to allow the passage of the shuttle
- Picking: passage of the weft threads through the tunnel formed by the warp threads
- Beating up: consolidation of the threads resulting from compaction of the weft thread that was just inserted against other threads that have already been woven and compacted

After these steps in weaving, the finished product is wound around the cloth beam and is ready for the finishing stages, inspection and packaging. Some woven geotextiles will receive the finishing treatment of calendering that will bond the threads in place and thus prevent the warp threads from fraying from the weft threads, which could cause displacement of the textile's fibres and thus have an impact on the mechanical and hydraulic properties of the geotextile.

### 3.2.4 Knitted geotextiles manufacturing process

The manufacture of knitted geotextiles involves a process in which a machine uses the mechanical movement of needles to intertwine one or more yarns together in the form of repeated loops. When these loops are linked one to another, we call them stitches. Each loop is made by the alternating movement of a needle. Modern industrial machines are equipped with hundreds of these needles working simultaneously or in sequence. The needles have a hook at their extremity serving to transport the yarn or yarns needed for the formation of the stitches. Depending on the technique used, the needles might be equipped with a latch that closes at certain stages in the knitting cycle and in this way create complex patterns of loops. Knitting is the easiest method of transforming yarn into a geotextile. As shown in Fig. 3.9, there are two types of knitting processes:

- Weft knitting
- Warp knitting

The knitting method most commonly used in the conventional textile industry is weft knitting. This method gives a knit structure in which successive loops are formed crosswise to the fabric. This type of knitting can be done using either a circular or a flatbed process. The circular process makes it possible to create a geotextile in the form of a continuous tube with no seams or lengthwise joint. This process can also produce fabrics with superior stretch qualities. Because of these two characteristics, the circular process is used to manufacture geotextile filter socks for use around perforated drainage pipes.

Warp knitting creates a structure in which successive loops are created lengthwise to the fabric. This method of working the yarn can create a structure that is, among other things, more closed and possessing higher tensile strength. The structure made using this production method will be much more stable and will not have the tendency to unravel, the way weft knitted textiles do when a yarn is cut. Warp knitting is done

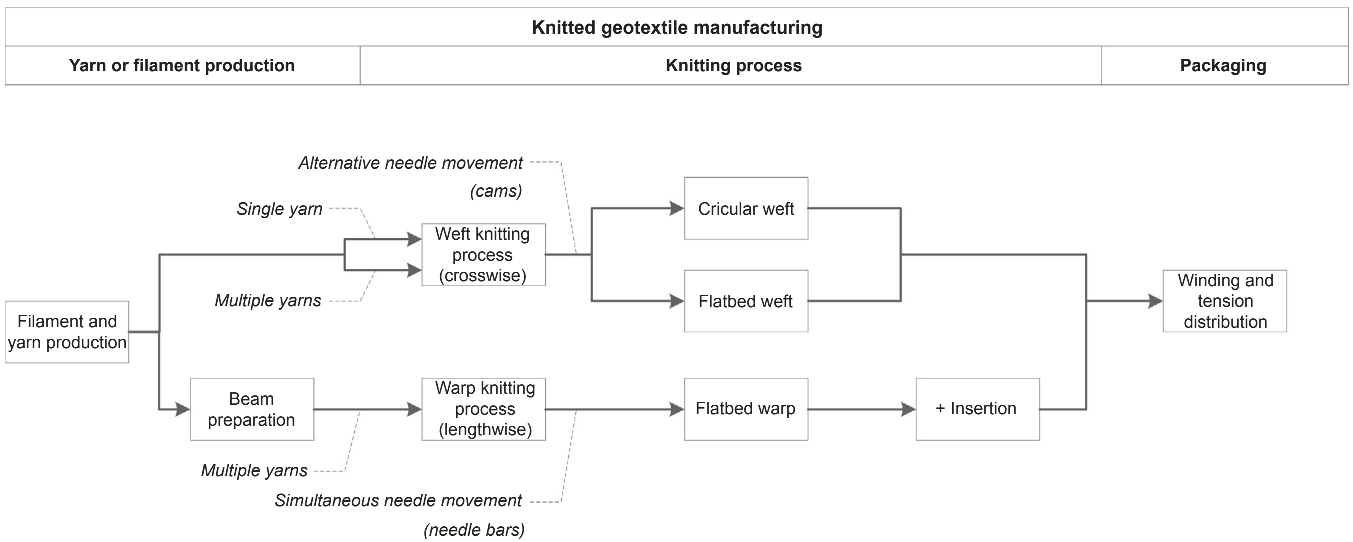



**Figure 3.9** Knitted geotextile manufacturing process flowchart.

using a flatbed process that allows the production of geotextiles with complex structures, including the insertion of filaments lengthwise, crosswise, or even diagonal to the fabric. When it includes these directional insertions, this type of knit is called a directionally oriented structure. Finally, in addition to permitting the creation of complex structures, warp knitting makes it possible to achieve superior knitting speeds and widths. Fig. 3.10 shows weft, warp and multiaxial knit structure types.

In the course of the knitting process, rows are generally produced by a series of adjacent needles, whereas wales are produced by the same needle. Although it is possible to produce a woven fabric using a single thread using weft knitting, in warp knitting a yarn is required for each needle, and thus for each wale. In addition, in warp knitting the yarns must be mounted on beams before they can be loaded onto the loom. In weft knitting, on the other hand, the yarns are fed directly from creels. In weft knitting production, needles equipped with butts follow the circular cams, which cause their alternating movement. In warp knitting, the needles are mounted onto a needle bar, which moves simultaneously in a linear fashion.

We speak of either single knits or double knits depending on whether one or two rows of needles are used alternately to work the same yarn. In the case of double knits, two sets of needles must be mounted at regular intervals, and their lines of action must cross at the point where the stitches are made. In flatbed machines, sets of needles are mounted parallel to and facing each other. In circular knitting, a set of needles is mounted vertically around a central cylinder and a second set is placed horizontally around a dial that is on top of the cylinder. The number of needles per unit of measure is called the gauge. For example, a gauge 8 loom has eight needles per linear inch.

The weight of a knit is determined by the dimension of the yarn and the gauge of the machine. The density of the knit is defined by the number of courses and wales that can be counted per unit length. This fabric characteristic is generally expressed by the number of courses per unit of length of the knit fabric or by the number of wales across the width of the knit. These values are expressed in units per centimetre or by inch, depending on the chosen unit of measure. The total density of stitches of the knit is thus defined by the number of loops or stitches per unit of surface area, or the number of courses multiplied by the number of wales.

Although knitting machines are much smaller than other geotextile manufacturing equipment such as nonwoven geotextile equipment, modern industrial knitting machines are complex production machines that draw on the latest technology to produce important volumes of high-quality knits. Knitting machines generally include the following components:

- The frame body of the knitting machine is generally made of steel and is designed to support the repetitive movement of the needles and the high-speed motor system.
- The yarn-feeding unit is the mechanical system installed on top of the frame or on the side of it. It directs the yarns through their guides and a system of tension control before leading them to the knitting unit.
- The knitting unit is the main element in the knitting machine. It includes the needles and their motor-driven system. Depending on the knitting process used (as described earlier), the needles are placed in a circle around the cylinder or in a line on the knitting bed. The movement

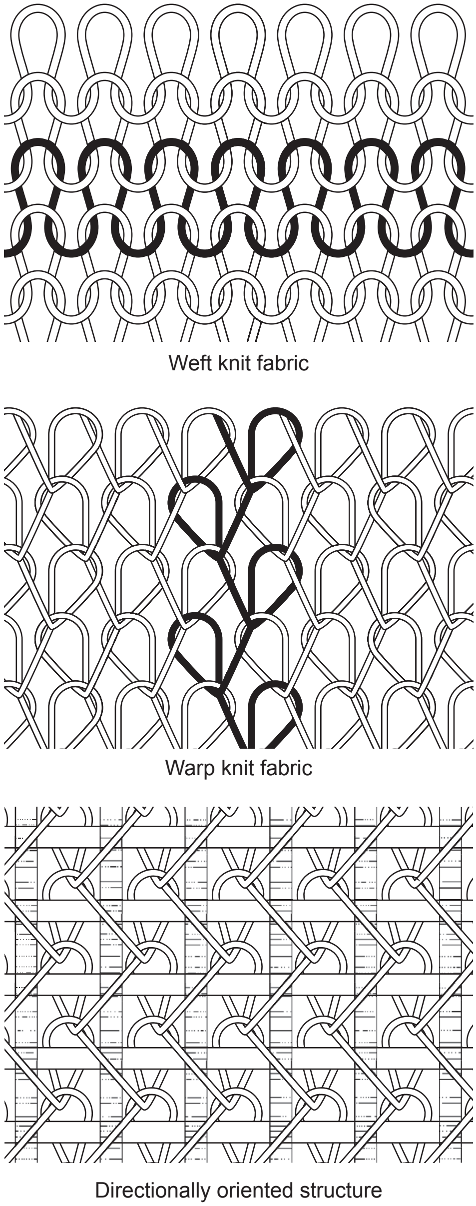



**Figure 3.10** Common structures for knitted geotextiles.

of the needles is normally generated either by the rotation of cams or by the alternating movement of the needle bars.

- Knitting needles are metallic needles with a point that is curved to form a hook. There exist different models of needles, depending on the type of knit required. Needles can have a latch under the hook that makes it possible to close the hook when the needle is descending, to hold the yarn in place and prevent other yarns from entering the hook. In warp knitting, we find small mechanical pieces called guide bars, which are used to direct the yarn around the needle.
- The take-up unit is the winding system that collects the knitted fabric and places it so that the tension will be distributed evenly in the material before it is wound on a core.
- Control modules: Recent machines are equipped with control computers that manage production parameters and the movement of mechanical parts associated with the needles so that all required movements will be performed for the given knitting method.

### 3.2.5 Composite geotextiles manufacturing process

Various manufacturing processes can be used to combine geotextiles together or with other types of geosynthetic products. The three main types of processes used are chemical (such as gluing), mechanical (such as needling or quilting) and heat processes (such as fusion or flame lamination). There are frequent developments in this field, and new geocomposite products and processes appear regularly on the market. In most cases, manufacturers make use of their own methods, which are protected industrial secrets, to protect their market. Many innovations have appeared in this field in recent decades; some are successful and others are less so.

## 3.3 Conclusion

As we saw in the last sections, the manufacturing processes for geotextiles are highly technologically advanced fields which have benefited from developments in technology and polymers to offer increasingly effective geotextile products. Since the first geotextile productions in the late 1960s, production speed has increased constantly, giving us the modern production lines we find today.

### 3.3.1 Trends and developments

The industry has seen a consolidation of equipment manufacturers and an increasingly important integration of technology. In the past, manufacturers purchased equipment from several different suppliers and were obliged to ensure its effective integration, but today geotextile production line installation projects are generally turnkey projects proposed as a whole by the equipment producers. This level of technological specialization, combined with the increasing production capacity of the new equipment, has had a significant impact on the amount of investment needed to produce geotextiles. It can easily require several million dollars or Euros to install a modern geotextile production line today.

The size of the investments needed, combined with production capacities and the maturity of the industry, have pushed conventional geotextiles to evolve into a range of commodity products in which specifications are increasingly standardized owing to national and international certifications. This industry trend towards a selection of commodity products, combined with a reduction in labour involved with the production, as a result of automation and increased volume, has also had an impact on the market price structures. Prices are connected to a global market and are mostly influenced by fluctuations in the price of polymers on the international market. In this context, globalization of the industry and international exportation have an ever-growing role in the balance of offer and demand.

Parallel to the tendency towards commodity products of standardized geotextile products, new technologies have also generated their part of innovation in the field of geotextiles. Manufacturers develop new products as a means to distinguish themselves from their competitors and to increase their profit margins because of new, higher-performing patented products. For example, some geotextiles are developed to integrate new functions, specifically when related to monitoring the performance of engineering projects. In fact, what is referred to as intelligent geotextiles can be used to support related functions. In this line of thought, we have seen geotextile products appear on the market that use fibreoptic technology to follow the distortion of the geotextile when it is exposed to mechanical stress during its use. Another geotextile product on the market contains a conductor of an electrical current that allows the geotextile to become an electrical conductor permitting such applications as controlling leaks by using geoelectric surveying in real time.

Other approaches to applications for geotextiles have seen strong progress. For example, cutting and assembling strips or cut patterns from geotextiles might also be seen as a sort of geocomposite. This has led to the creation of geotextile tubes, honeycomb-patterned containment cells and pots, for growing plants, made from geotextiles.

### *3.3.2 Future trends and macroscopic tendencies*

Considering that geotextile production is increasingly taking on an international scale beyond national boundaries, one can believe that the quest for performance, cost reduction and increased productivity will drive future developments and investments in this industry in years to come. Continuous improvement processes, value-added products and cost reduction should stimulate the manufacturers of geotextile products and of geotextile equipment. Reduction in down time and maintenance time are also opportunities to reduce the costs identified by manufacturers. Improved quality and process control techniques such as automatic product inspection, use of electronic servo-systems and implementation of statistical process control techniques should also continue to advance in the geotextile industry.

Certain developments in the industries of polymers, additives and fibres should result in products with increased performance. Whether seen from a perspective of technical or economic performance, geotextiles will be developed that will give improved performance for the same price. This should lead to a reduction in the ratios of raw materials and an increase in technical performances per dollar spent by the client.

To confront the increasing complexity in the design of civil engineering projects and limit the high costs involved in the use of multiple layers of geotextiles, we will see the increased use of geocomposites. These multimaterial products make it possible to combine several types of functions in one product (eg, reinforcement plus drainage, reinforcement plus separation) or to massively increase the capacity of a given function (eg, drainage, puncture resistance). The list of geocomposites available on the market is already impressive and it will continue to be completed with the addition of new products. This industry is not about to slow down as long as technical and monetary requirements become increasingly demanding for civil engineering, mining and environmental projects.

Finally, environmental considerations should have a growing role in society's concerns. As such, we could probably see an increasing number of products made from recycled, postconsumer fibres and natural fibres. In coming years, we should see new environmentally conscious products and methods that are more respectful of the environment (eg, waste reduction, reduced energy consumption) and the development of products that take into account the global product's life cycle. Geotextiles are considered to be a sustainable development solution allowing for a smaller environmental footprint of projects with a reduction in the use and transportation of natural resources combined with improved performance and the longer lifespan of works using this type of geosynthetic solution. As it will be explained in more detail in chapter "Sustainability Aspects of Using Geotextiles," these environmental advantages can be calculated and should be taken into account alongside economical advantages in projects involving geotextiles.