Introduction to Geosynthetics
Geosynthetic Functions

There are six main functions that geosynthetic materials can provide and many products provide one or more of these, particularly the Geocomposites which, as the name suggests, are made up of multiple components.

The six functions are:

- **Separation**: Preventing the intermixing of soil types or soil/aggregate to maintain the integrity of each material yet still allow the free passage of liquids/gasses. Commonly used in between subbase/subgrade and around drainage materials.

- **Filtration**: Restraining soil particles subject to hydraulic forces whilst allowing the passage of liquids/gasses. This function is partnered with separation.

- **Drainage**: Allowing fluids and gasses to flow through the plane of the material. Commonly provided by components in Geocomposites for surface water runoff or for gas collection under membranes.

- **Protection**: Preventing or limiting localised damage to an adjacent material, usually a geomembrane used to line a lagoon or landfill.

- **Reinforcement**: Providing additional strength to soils to enable steep slopes and soil structures to be constructed over weak and variable soils.

- **Containment/Barrier**: Isolating one material from another. The most frequent use of this function is in landfills where impermeable linings prevent contamination of surrounding soils.
Principal Categories of Geosynthetics

Geocomposites

Permeable
- Geotextiles
  - Woven
  - Nonwoven
  - Knitted
- Geogrids
- Geonets
- Geofoam

Impermeable
- Geomembranes
  - Polymeric
  - Bituminous
- Geokuspates
- GCL
  - Geosynthetic Clay Liner

Geocomposites
The Extrusion Process

Almost all geosynthetic manufacturing starts with an extrusion process, whether this is the extrusion of fibres to be made into geotextiles or sheet to be made into membrane or grids. The extrusion of plastics is a high-volume manufacturing process in which raw plastic is melted and formed into a continuous profile. In the extrusion of plastics, the raw compound material is commonly in the form of pellets (small beads, often called resin) that are gravity fed from a top mounted hopper into the barrel of the extruder. Additives such as colorants and UV inhibitors (in either liquid or pellet form) are often used and can be mixed into the resin prior to arriving at the hopper.

At the end of the extruder the polymer passes through a die, and is then extruded into the required shape. The extrusion technique is very versatile and can be adapted to produce a wide range of products, merely by using the appropriate dies. Extrusion is a process used to create objects of a fixed cross-sectional profile. A material is pushed through a die of the desired cross-section.

Materials are often drawn to impart strength through molecular orientation. This process is particular relevant in the manufacture are high strength fibres and filaments, and in the drawing process used in the manufacture of high strength grids.
Geotextiles

Geotextiles are split into two principal categories, nonwoven & woven. They are permeable fabrics which, when used in association with soil, have the ability to separate, filter, reinforce, protect, or drain. Geotextiles are typically manufactured from polypropylene or polyester, although other materials are used. The manufacturing method and the materials used have a significant effect on the corresponding properties of the material and therefore the selection of the right product type is paramount.

Nonwoven Geotextiles

A nonwoven geotextile is made of directionally or randomly orientated fibres which are laid down in a web and bonded together in a variety of ways. The importance of bonding is such that specific nonwoven processes are often identified by referring to the bonding step alone. This is not adequate, of course, but is common practice. Most nonwoven experts agree that four major elements characterise a nonwoven structure.

- **Fibre**: the building block of the fabric structure (see durability of geotextiles)
- **Web Formation**: how fibres are assembled
- **Bonding system**: the means for holding the structure together
- **Finishing treatment**: the additional chemical/mechanical or thermal treatments

Web Formation

The manufacture of any nonwoven geotextile begins within the formation of a web. In this web formation process fibres or filaments are either deposited onto a forming surface to form a web or are condensed into a web and fed to a conveyor surface. The formation of a web involves converting staple (cut) fibres or filaments into a web assembly which is the precursor to the finished fabric.

The structure and composition of this web formation will have a strong influence on the dimensions, structure and properties of this finished fabric. For example, the orientation of the fibre structure will have a significant impact on the directional strength of the finished fabric. Fibre orientation is a critical parameter in GEOfabrics HPS products to ensure that tensile strength remains isotropic.
Geotextile web formation is split into two principal methods, these are:
- Dry Laid/Carded Webs
- Polymer Laid/Spunlaid Webs

**Dry Laid/Carded Webs**

In dry-laid web formation, staple (cut) fibres are carded (combed) and then cross lapped (folded) and then bonded in a subsequent stage. Fibres, which are normally supplied in dense-packed bakes, are usually opened prior to carding. The carding process involves the working of the fibres over large cylinders wrapped in a toothed wire, the purpose of which is to disentangle and mix fibres to form and homologous web of uniform weight per unit area. This is achieved through a series of fibre opening and layering actions accomplished by the interaction of each of the toothed rollers.

The fibrous web is then transferred from side to side on to a lower conveyor which runs perpendicular to the infeed. This layering of the carded web allows for finished fabrics of varying weights and widths to be produced.

**Polymer laid Webs**

Polymer laid, spun laid or spun melt nonwoven geotextiles are manufactured using an extrusion spinning process whereby the filaments are directly collected to form a web.

The principal factor in the manufacture of a spunbonded fabric is the control of four simultaneous, integrated operations: filament extrusion, drawing, lay down and bonding. The first three operations are directly adapted from conventional man-made filament extrusion and constitute the spun or web formation phase of the manufacturing process. The last operation of web bonding process can vary, they tend to be either mechanically bonded or thermally bonded.

The weight of the finished fabric is varied by a simple speed change, altering the amount of fibre on the transport conveyor.

**Web Bonding Methods**

Nonwoven binding methods can be mechanical, chemical or thermal. The method and degree of bonding is the principal factor in the determination of the fabrics mechanical properties and filtration properties. In some fabric structures more than one bonding process is used.

Although there are a number of bonding options available within nonwovens technology, not all of them are commercially utilised in the manufacture of geotextiles. The two principal methods of web binding in the geotextiles are mechanical bonding and thermal bonding, these can be used singularly or together.

**Mechanically Bonded/Needlepunched**

In a mechanical binding process a fibrous web is manipulated mechanically so that entanglement of the constituent fibres occurs and is carried out to such an extent that fabric integrity results from the interlocking. The major bonding in systems of these types is friction. There are a number of specific processes involved in providing sufficient mechanical interlocking of fibres to adequately bond a nonwoven structure including the following:

- Fibre entanglement via water jets
- Needlepunching
- Stitch-Bonding

The vast majority of mechanically bonded geotextiles that are commercially produced are manufactured using a needlepunching process. The needlepunching process involves the use of barbed needles which penetrated the fibrous web driving and facilitate the entanglement process. As this process continues, generally from both sides, the web consolidates and becomes highly densified.
Geotextiles that are bonded using this process alone are usually characterised by their high strength and high elongation at break. It should be noted that additional finishing treatments that follow this process can significantly alter the properties of the fabric.

**Thermally Bonded**

Thermal bonding requires the presence of a thermoplastic component whereby heat is applied until the component becomes viscous or melts. The component may be present in the form of a homofil fibre, powder, film, hot-melt or as a sheath part of a bi-component fibre. The polymer will flow by surface tension and capillary action to the fibre to fibre crossover point where the bonding regions are formed and then fixed by subsequent cooling.

Thermally bonded nonwovens are manufactured both from entirely thermoplastic materials and from blends containing fibres that are not intended to soften or flow on heating. The binder material are produced in many different forms including fibre or filament. The physical form of the binder material has an impact on its distribution throughout the fibre matrix. Both the amount and type of binder material will have significant impact on the fabrics short and long term properties.

**Calendaring**

Thermal calendaring is a process whereby the nonwoven web is passed continuously between two heated cylinders, often under pressure. Both cylinders are usually heated to a point that exceeds that of the melting point of the material. Calendars are extensively used for finishing of nonwovens as well as thermal boning. Normally, after calendaring the fabric is passed over cooling rollers.

The result of calendaring is a compaction of the structure as the fabric is compressed, a decrease in thickness and stiffening. Although this process can often increase tensile strength the loss in elongation and thickness can have a negative effect of the materials mechanical durability.
Woven Geotextiles
Woven geotextiles are manufactured by interlacing two parallel sets of elements at right angles to form a coherent structure. The properties of the geotextile will be a function of the elements used and the weave pattern.

Weaving can be summarised as a repeat of three primary actions:

- **Shedding**: where the ends are separated by raising or lowering heald frames to form a clear space where the pick can pass.

- **Picking**: where the weft or pick is propelled across the loom by hand, as air-jet, a rapier or a shuttle.

- **Beating-up**: where the weft is pushed up against the fell of the cloth by the reed.

The elements that are used to weave a geotextile may be produced in a variety of ways:
- Slit Film Tape
- Extruded Flat Tape
- Multifilament Yarn
- Tape Yarn
- Monofilament
- Combination Weaves

Woven geotextiles vary significantly in both quality and strength, from poor quality low strength filters to relatively high quality reinforcing geotextiles. GEOfabrics utilises the unique qualities of high strength woven geotextiles in its composite materials (discussed later).

Extruded Flat Tape
An extruded flat tape is manufactured using the screw extrusion process previously described. The tape is drawn off the extruder by a bank of rollers which rotate at differing speeds to apply tension. This tension orientates the molecules in the polymer to impart strength. The drawing process will reduce the thickness of the tape so that it can be woven into a relatively strong fabric.

Slit Film Tape
A slit film tape is similar to an extruded film tape with the principal difference being that rather than being directly extruded from a tape a sheet is produced and then slit down into narrow strips. The same drawing process is used to impart strength into the weaving element. It is common place to fibrillate the tape by adding spall nicks. This fibrillation process can allow for a tighter weave and a higher strength finished fabric.
Tape Yarn
A yarn uses a slit film tape which is then wound into a yarn to allow for the production of heavier, stronger woven geotextiles. The fibrillation process allows for the tape to be twisted and spun into a yarn which provides a much stronger weaving element.

Monofilament
Although, strictly speaking, the term monofilament could encompass flat tapes, it generally refers to extruded elements with a circular cross section. The manufacturing process is basically the same as that which is used to produce an extruded flat tape except the die head is shaped differently. The finished fabric would have a very different structure to that of a tape, normally with differing filter properties.

Multifilament
A multifilament yarn uses similar technology to that which is used to produce a fibre for a nonwoven geotextiles, except rather than lay the fibres down randomly the fibres are spun into a yarn and used in the weaving process. As with a fibre manufacturing process, the elements are drawn to impart strength into the weaving element.

Combination Weave
The weaving process is such that the warp and weft yarns do not necessarily need to be the same type of weaving element. It is therefore possible to manufacture woven geotextiles which combine different combinations to obtain a variety of finished fabrics.

Knitted Geotextiles
A knitted geotextile consists of a series of interlocking loops of yarn. The fabric is formed when a loop of yarn or monofilament is drawn through a previously formed loop. There are two methods to produce a knitted fabric:

- Weft Knitted
- Warp Knitted

Warp Knitted
With warp knitting, the preparatory processes are more involved because the yarns have to be first assembled onto a warp beam, then once on the machine, threaded through warp guides. The warping process must be undertaken with great care and precision to ensure trouble free knitting. Warp beams are then loaded onto the machine. After passing the warp sheet over the tension rails, the threads are introduced through individual warp guides, attached to the guide bars.

All the warp threads from an individual warp guides, attached to the guide bars. All the warp threads from an individual beam are allocated their own guide bar. The guide bars are then set up on the machine in readiness for knitting.

Weft Knitted
This is a method of making a fabric in which loops made by each yarn are formed substantially across the width of the fabric. This method is characterised by the fact that each yarn is fed more or less at right angles to the direction in which the fabric is produced. Weft knitting is a relatively simple method of forming a fabric, because a single package of yarn can furnish a multiplicity of fabric.
Geogrids

Integral Junction Geogrids
There are two principal methods for the production of an integral junction geogrids, both methods involve the drawing of a sheet material with holes to create the apertures. The drawing process of the sheet material creates a very rigid structure with high strength and stiffness. These sheets can either be drawn in one or multiple directions to determine the structure. The principal difference in the two methods is one is drawn from a flat sheet and punched and the other is made on a circular die with a piston creating the holes. The circular sheet is then slit to create a flat rolled product, both are drawn and heated in a stenter oven.

Fused Junction Geogrids
Fused junction geogrids normally consist of strips of high tenacity polyester that have been coated in polypropylene to maintain durability. The machine and cross machine elements are bonded together, normally by sonic welding.

Woven Junction Geogrids
Woven geogrids comprise of a load bearing central reinforcing component coated in an outer protective material. The most common of these reinforcing components is a high tenacity polyester. Where the machine and cross machine elements cross they are interweaved at multiple levels. The outer coating may be polypropylene or PVC which will provide added protection against environmental exposure.
**Geonets**

Geonets consist of integrally connected parallel sets of polymer ribs overlying similar sets at various angles for in-plane drainage of liquids or gases.

Geonets elements cross at angles typically between 60° to 80° to form a diamond shaped aperture. They are typically manufactured using a counter rotating die process developed by Netlon Limited. The counter rotating die consists of an inner circular die that is mounted inside a tubular sleeve. The outer sleeve has longitudinal slots on the inside while the inner tubular section has slots on the outside. Both the sleeve and the tubular section counter rotate, the strands of polymer cross over and form junctions. The net is extruded as a tube which is cuts and drawn to create a flat rolled product.

It is common practice for the nets to be supplied as part of a composite product, typically with a geotextile bonded to one or both sides, however some applications allow for the net to be supplied in isolation.

There are three categories of geonets.

- Biplanar Geonets
- Triplanar Geonets
- Box Type Geonets

**Biplanar Geonets**

These are the original and most common types and consist of two sets of intersecting ribs at different angles and spacing. The ribs themselves are of different sizes and shapes for different styles.

**Triplanar Geonets**

These have parallel central ribs with smaller sets of ribs above and beneath mainly for geometric stability.

**Box Geonets**

These newer geonet structures have either box shaped channels or protruding columns from an underlying support network. Box nets are formed in a different process, similar to that of an extruded geogrid.
Geomembranes

Geomembranes are generally made of polymer sheets that are extruded flat or as a tube that is split in the machine direction. However, they can also be made by impregnating a geotextile with asphalt, or as multi-layer bitumen composites.

Geomembranes generally serve a singular purpose, to act as a barrier to liquids and gasses, as such geomembranes are generally impermeable \((10^{-10} \text{ m/s})\). Geomembranes are used in applications where it is necessary to prevent the loss of water or toxic materials. Broadly speaking, there are four types of geomembrane split into two categories. Geomembranes manufactured in situ (i.e. on site) and geomembranes that are factory manufactured using an extrusion process which can vary. Within each class, there are two sub-classes: non-reinforced and those with a reinforcing textile.

Extruded geomembranes are manufactured using relatively basic manufacturing processes, the manufacturing of geomembranes begins with the production of the raw materials, which include the polymer resin (plastic or rubber), and various additives such as antioxidants, plasticizers, fillers, carbon black, and lubricants (as a processing aid). These raw materials (i.e., the "formulation") are then processed into sheets of various widths and thickness by extrusion, calendaring, and/or spread coating.

The formulation can be a plastic (e.g. PVC, HDPE, LLDPE) a rubber (e.g. EPDM, EVA) or a combination of the two. Two different types of materials are used to provide impermeability.
Geocuspates

Geocuspates are used to provide a void space for the passage of either a liquid or a gas. The manufacturing process involves the forming of a sheet which is formed into the either cups or studs, with a variety of heights and spacing which determine the size and area of the void. It is common for a cuspate to be used as a component in a Geocomposite, used in conjunction with a geotextile filter.

The primary function of the geotextile on the upper side is to act as a filter/separator which maintains the void space. The function of the secondary textile, on the underside, is to improve the interface friction between the geocomposite and the materials that it is in contact with (often a geomembrane barrier/or a geosynthetic clay liner). The inclusion of the geotextile is known to increase the angle of friction by as much as double.

The interface friction value between opposing geocomposites and geocomposites with soil is a critical design factor for determining slope stability. A design value is often given within a site specification, this will determine what product can be accepted within a tender. This is normally measured principally performance test known as a shear box with a value specified within the design.

The sheet is formed in an extrusion process, whereby semi-molten polymer is extruded through a flat die, typically at widths of 1-2m and thicknesses from 0.4-2mm.

The sheet is formed into cusps which create the void, there are two principal forming methods, Vacuum forming and Roller Forming.

Vacuum forming is a simplified version of thermoforming, whereby a sheet of plastic is heated to a forming temperature, stretched onto a single-surface mould, and forced against the mould by a vacuum (suction of air). An Alternative to Vacuum forming involves a continuous process where semi-molten polymer is formed between two corresponding rollers with male and female forming points.

There are several aspects that will determine the properties of the finished cuspate:
- The polymer
- The Additives
- The sheet thickness
- The shape and size of the cusp.
GCL’s

A GCL is a uniform layer of sodium bentonite sandwiched between two layers of geotextile. When hydrated a GCL will swell to heal and seal itself around a rip or puncture. The geotextiles are bonded either using an inert adhesive, stitching or by the needlepunching process. It is important that there is a uniform layer of the bentonite for effective protection and to ensure that there are no pockets or voids that could be a conduct for liquids.

When fully hydrated a GCL is able to swell to more than 10 times its dry volume. The sodium bentonite performs the primary function of the liner. When hydrated they are effective as a barrier for liquid or gas and are commonly used in landfill liner applications often in conjunction with a geomembrane. The function of the geotextile is to allow the bentonite to be installed quickly and uniformly.

When specifying a GCL it is important that:

- A low permeability can be achieved in the GCL and the seams at the confining stress particular to the project.
- Performance properties are specified, not material properties
- The bentonite in the composite has adequate swelling properties to self-seam and heal.
- The GCL requires no treatment of seams with additional dusty granular bentonite or bentonite paste to form an impermeable seam.
Geocomposites

A Geocomposite is a combination of one or more geosynthetics which when effectively selected can allow the user to benefit from multiple features in an optimal manner at minimal cost. The use of a composite material allows for expanded functionality in a single material, and can significantly increase construction speeds when compared with alternatives.

There are three principal methods for combining materials to produce a geocomposite:

**Adhesive Bonding**: In this process an adhesive is applied to materials to bond them together. There are a number of methods in which an adhesive can be applied to a substrate, the principal ones are spray, bath and roller and pressure. The selection of an appropriate adhesive is critical to both the short term and long term properties of the finished composite.

**Heat Lamination**: This involves the passing of materials (normally a thermoplastic) over a heat source to create a thin layer of molten polymer, following which the material is quickly pressed against its counterpart while still in its molten state.

**Stitching**: In this process components are stitched together using high strength yarns, much in the same way that fabrics are stitched together to manufacture traditional textiles. This is an effective way of combining materials, it can however be a very time consuming manufacturing process.

**Welding**: Most thermoplastics can be effectively welded together, there are a number of ways in which this can be done. When done effectively, the strength of a welded section can be close to the strength of the material itself. A common welding method is ultrasonic welding, where high-frequency ultrasonic acoustic vibrations are locally applied to workpieces being held together under pressure to create a solid-state weld.

Although the combinations available for Geocomposites are only limited to the imagination of the user, there are some common multiples that are effectively used on a wide basis:

**Geotextile/Geonet Composites**: Geonets are often laminated to one or both sides of a geonet. In this combination the geonet provides a void space for the in-plane flow of liquids/gasses and the geotextile provides the filtration/separation function.

**Geotextile/Geomembrane Composites**: Geotextiles are laminated to one or both sides of a geomembrane to provide protection from both short term installation damage and long term strain. The main advantage of using a composite is the vastly increased installation speeds.

**Geotextile/Geogrid Composites**: Geotextiles are bonded to grids to provide an additional filtration function and allow for the separation of finer soils. It is recommended that a geotextile with a high elongation be selected to ensure it does not inhibit the functionality of the geogrids.

**Geotextile/Polymer Core Composites**: An extruded quasi-rigid plastic sheet, it can be extruded or deformed in such a way as to allow very large quantities of liquid to flow within its structure; it thus acts as a drainage core. The core must be protected by a geotextile, acting as a filter and separator, on