The Role of Geotextiles in Geosynthetic Applications

R. D. Anandjiwala[1,2]
[1]Chief Researcher and Research Group Leader: Nonwovens and Composites Research Group, Polymers and Composites Competence Area, CSIR Materials Science and Manufacturing, P.O. Box 1124, Port Elizabeth 6000, South Africa. ranandi@csir.co.za
[2]Department of Textile Science, Nelson Mandela Metropolitan University, Port Elizabeth, South Africa. Rajesh.Anandjiwala@nmmu.ac.za

ABSTRACT

Nonwoven geotextiles are complex three-dimensional structures formed by the random arrangement of fibres. They are permeable and compressive textile materials and belong to the geosynthetic group, which also includes geogrids, geonets, geomembranes, and geocomposites. The design of appropriate geosynthetics involves careful consideration of the functions of the various constituent materials in terms of the intended end-use. A rational design, which effectively combines geotextiles with other geosynthetics, is required. Needlepunched nonwoven geotextiles are extensively used in civil engineering applications, including road and railway construction, landfills, land reclamation, sea defence, and reinforcement of clay slopes. Such applications require geotextiles to perform more than one function, including filtration, drainage, and separation. The filtration function of geotextiles is to retain the soil, while allowing the passage of the liquid. The drainage function of geotextiles is to transmit the liquid in the plane of the fabric without the loss of soil particles. Therefore, the filtration and drainage functions differ mainly in terms of direction of liquid flow. The separation function of geotextiles involves segregation, followed by retention of soil particles. Thus, the geotextile structure should be designed to fulfil the criteria demanded by the specific end-use.

1. INTRODUCTION

Sub-Saharan African countries have received unprecedented opportunities from the United States under its African Growth and Opportunity Act (AGOA) to export manufactured textiles and clothing duty free to the USA. Nevertheless, in spite of the initial enthusiasm, there has hardly been a noticeable increase in export volume and value over the past seven years. The role of geotextiles in geosynthetic applications should be explored to counter balance a loss in trade besides supporting the local manufacturing base in Africa.

Geotextiles is one of the important market segments of technical textiles which are not yet fully explored in Sub-Saharan Africa, despite being widely used in many civil engineering applications within the continent. Nonwoven geotextiles are complex three-dimensional structures formed by the random arrangement of fibres bound by mechanical, chemical or thermal bonding. They are permeable and compressive textile materials, and belong to the geosynthetic group, which also includes geogrids, geonets, geomembranes, and geocomposites.

The design of appropriate geosynthetics involves careful consideration of the functions of various constituent materials in terms of the intended end-use. A rational design, which effectively combines geotextiles with other geosynthetics, is required. Needlepunched nonwoven geotextiles are extensively used in civil engineering applications, including road and railway construction, landfills, land reclamation, sea defence, and slope stabilization. Such applications require geotextiles to perform more than one function, including filtration, drainage, and separation. The filtration function of geotextile is to retain the soil while allowing the passage of the liquid. The drainage function of geotextiles is to transmit the liquid in the plane of the fabric without the loss of soil particles. Therefore, the filtration and drainage functions differ mainly in terms of direction of liquid flow. The separation function of geotextiles involves segregation, followed by the retention of soil particles. Thus, the geotextile structure should be designed to fulfil the criteria demanded by the specific end-use. For instance, the geotextile products used in rail track construction must possess high strength, excellent filtration and drainage capacity. This presentation will discuss the various opportunities that can be explored, through research and development, in various cross-cutting industry segments, particularly for nonwoven industries catering for geosynthetic applications (Hwang et al 1998, 1999).

1.1 Geosynthetics

According to SANS ISO 10318:2013, geosynthetics is a general term used to describe a product which is produced with several components made from raw material derived from synthetic or natural origins. These components may be in the form of a sheet, a strip or three-dimensional structure employed in contact with soil and/or other materials for geotechnical and civil engineering applications. The major products belonging to geosynthetic family include geomats, geonets, geogrids, geocells, geostrips, geoliners, geospacers, geomembranes, geotapes, geotextiles, geocomposites, etc (Figure 1). The major functions of geosynthetics are drainage, filtration, protection, reinforcement, separation, erosion control, barrier, etc

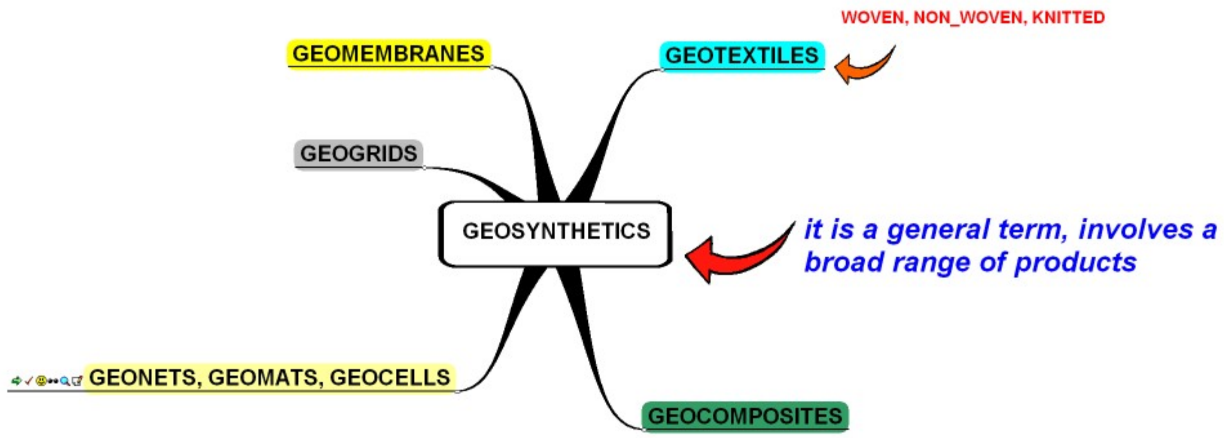

Figure 1: Geosynthetic Products

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Different geosynthetic materials, such as low permeability membranes, are used as barriers; geotextiles for filtration, separation and protection; geonets and three dimensional meshes for drainage and soil stabilisation, and high strength geogrids, tapes and woven/knitted geotextiles for reinforcement. During the last few decades, these geosynthetic materials have witnessed considerable development in civil and environmental engineering applications, due to the discovery of new polymeric materials. The role of these materials is no longer to provide only filtration, drainage, separation, reinforcement and barriers; but to provide several functions simultaneously, as an optimized assembly (also termed composites), for delivering specific end-use performance (Rowe, 2000). For example, some such assemblies, in the form of composites, used now-a-days are:

- geotextile-geonet combined to provide filtration and drainage,
- geotextile-geogrid combined to provide drainage and reinforcement, and
- geotextile-geomembrane composites to provide low permeability membranes, with their own protective barriers to enhance puncture resistance and thereby prevent damage.

Nevertheless, despite many such materials being available today, achieving desired performance, through properly optimised geosynthetic design is becoming an important exercise. Selecting the required engineering properties in individual component and adopting a rational design, are important in achieving cost-effective applications which meet the desired end-use performance, and thereby replace the traditional materials. Moreover, laying and installation techniques should be also accounted for when designing a geosynthetic system. It has been reported that newer knowledge has made it possible to design geosynthetics with tailor-made properties to achieve solutions that were not possible in the past, for example reinforcement over a large void/gap and stabilization of very soft soils (Lawson et al, 1996).

In the following sub-section, important geosyntehtic materials are briefly described, with a particular emphasis on geotextiles:

1.1.1 Geogrids

The geogrid is a category of planar geosynthetics which is characterised by uniformly distributed interconnected elements of various shapes and sizes to provide in plane voids, with their main function being to reinforce and support the assembly and the soil. The apertures within the grid allow direct contact with the soil, so as to increase the interaction between the geogrid and soil, thereby allow vertical drainage. Some geogrids are designed to overlay on asphalt and waterproofing, or for separation and stabilization. Geogrids are also applied as gabions and sheet anchors, between geotextiles and geomembranes, and to construct a bed for fillings or embankments over soft soils. Depending upon the requirement, geogrids are mainly produced from a variety of synthetic polymers, although the use of some natural polymers and bio-based products are also being studied.

1.1.2 Geomembranes

Geomembranes are permeable or semi-permeable membranes, designed to provide barrier, containment and other geotechnical functions. They have been used for at least 60 years, and have found wide-spread acceptance in many such applications. A wide variety of polymeric membranes with tailor-made properties, such as resistance to ultraviolet light, ozone and microorganisms in soil; are available in the market.

1.1.3 Geonets

Geonets are 2-dimensional or 3-dimensional cellular structures having a regular network of integrally connected overlapping ribs, forming large voids compared to the volume of the constituents. They are applied in combination with other geosynthetics, notably geotextiles, for filtration, drainage and protection. They are typically applied for drainage of highways, landfill, underground structures, gardens etc.

1.1.4 Geocells

Geocells are 3-dimensional expandable cellular panels, specially engineered for protection and stabilization applications. They are often applied to improve the function of the standard materials in erosion-control. In such expandable 3-dimensional cellular structures, filling materials can be placed and then compacted; which provides a drainage system along with confinement through reinforcement. Such systems provide improved performance in terms of structural stabilization and functional behaviour of soils and filler materials. They are made from high density polyethylene, polyester or other polymeric materials.

1.1.5 Geosynthetic Clay Liners (GCL)

One of the most widely exploited applications of membranes, liners and covers, in landfill and waste disposal sites, is in Geosynthetic Clay Liners (GCL). The GCLs, consisting of a thin layer of clay bonded to a layer or layers of other geosynthetic materials, like liners and geotextiles, are becoming more popular than traditional compacted clay liners (CCL). According to Koerner (1998), there are a variety of different GCLs. The GCL is an impermeable, needle-punched nonwoven and bentonite (clay) composite which can be employed in high-stress applications to contain a variety of liquids, from municipal solid waste leachates to fuel oils. It is manufactured by encasing processed clay (typically bentonite), either bonded to a geomembrane by glue or fixed between two sheets of geotextiles by adhesives, stitching or needlepunching, as shown in Figure 2.

Figure 2: Typical Construction of GCLs (Source: US Environment Protection Agency)

The use of GCLs is steadily increasing, because they offer significant benefits, such as cost-effectiveness, ease of manufacturing, laying and installation, superior performance and acceptance under regulatory system.

1.1.6 Geotextiles

Geotextiles are permeable fibrous structures used for filtration, drainage, separation, reinforcement and stabilization in civil engineering applications (Denton and Daniels, 2002). Geotextiles are normally combined with other geosynthetic materials to provide cost-effective solution to meet specific design requirements and functions.

Geotextiles are broadly classified into woven, nonwoven and knitted structures; employed according to the performance requirement. Woven geotextiles are stronger, resist initial deformation and are less extensible; needle-punched geotextiles are relatively open and porous structures with high permeability, high elongation and conformability, while knitted geotextiles are strong but generally very extensible. Besides needle-punched nonwoven materials, thermally spun-bonded nonwoven fabrics are also employed, due to their high strength and high modulus compared to the needle-punched fabrics.

Nonwoven geotextiles are traditionally mainly made from synthetic fibres, such as polypropylene, polyester, polyethylene and polyamide; nevertheless, due to post-service life disposal and environmental concern, natural fibres are increasingly being preferred in some applications. Besides being derived from natural renewable resources; natural fibres have high strength and modulus, low breaking extension and elasticity, and are relatively inexpensive and biodegradable (Lekha, 2004). In comparison to synthetic fibres, natural fibre yarns and fabrics generally suffer low levels of creep during use. As reinforcement and support structures, geotextiles must possess high tensile strength; hence plant fibres such as sisal, jute, hemp, abaca, ramie and coir, offer potential in replacing some of the synthetic fibres, although the use of a specific fibre will be dependent upon the requirements of the intended applications (Rawal et al, 2010).

The performance requirements of geotextiles – both as stand-alone and as a component in geosynthetic composites – are broadly classified into the following categories:

- Reinforcement – this function is achieved by providing reinforcement to weak soil by a high strength fabric. The presence of the geotextile increases the cohesion between the grains of the soil, thereby improving load-transfer, and, as a result, the composite can withstand higher loads. This complex reinforcement phenomenon is attributed to the interactions of soil and geotextiles (Adanur and Liao, 1998).
- Separation – this function is achieved by separating the fine soil and the coarse material. The geotextile separates the various materials, and prevents their mixing under applied loads. For example, gravel is prevented from penetrating and mixing with soil if they are separated by a geotextile layer. The hydrophobic nature of some of the olefin fibres can also be exploited to prevent the moisture from seeping through, and disturbing, fine soil structures.
- Filtration – this function is achieved by arresting particles carried by liquid passing through the geotextile medium. The geotextile retains soil particles and prevents them from being carried away by the flowing water.

- Drainage – this function is achieved by collecting and re-directing flowing liquid, or gas towards the desired destination, without the loss of soil particles. The porous geotextile structure, with good permittivity and filtration properties, can act as a good drainage medium.

2. APPLICATION OF GEOTEXTILES

Application of geotextiles, both from natural and synthetic fibres, is experiencing resurgence, due to the demand for improved quality in civil and environmental engineering. Both short-term and long-term applications require appropriate geotextiles made from natural or synthetic fibres.

For a short term applications, such as slope stabilization, vertical drainage, wick drain, soil erosion control, water shed management, etc.; natural fibres, such as jute, coir and wood, have provided the desired performance at an acceptable cost. In such applications; after use, the geotextiles need to decompose without adversely affecting the visual appearance of the site. Using natural fibres in geotextiles is not desirable when long-term durability is required, due to their susceptibility to degradation from microbial attack in soil, which is aggravated by water, rain and sun. A number of studies, involving natural fibre based geotextiles, have been undertaken, and readers are referred to an excellent review by Rawal et al (2010).

For long-term applications, synthetic fibres; such as polypropylene, polyester and polyamide; are suitable due to their cost-effectiveness, and strength, and their resistance to microbial attack, abrasion and degradation during exposure to soil and water. While some synthetic fibres, such as polypropylene, have poor resistance to Ultra Violet (UV) radiation; they suffer degradation from long exposure to sunlight. In general, however, they have good mechanical properties and fatigue-flexure resistance (Barnett and Slater, 1991).

The choice of a specific geotextile will largely depend upon the soil and hydraulic conditions to which it will be subjected, besides fulfilling the required functions, either as a stand-alone product, or as a component in an overall geotechnical assembly. Some of the important applications of geotextiles are:

- Railway tracks
- Landfill sites
- Land reclamation
- Pavement of roads
- Embankments
- Drainage
- River and sea bank protection
- Slope stabilization
- Lakes and water storage dams
- Linings and covers
- Sub-soil separation
- In perpendicular and in-plane liquid flow applications

2.1 Performance of Geotextiles

The design of geotextiles, in order to fulfil the desired performance, is very important. The failure of geotextiles in use can be expensive. Therefore, a judicious choice, in terms of fibre, manufacturing method, laying and test method, is required for critical assessment, before conducting actual field trials. The laboratory evaluation of the technical performance of a geotextile should provide a good indication of its performance in use and the assessment of the effectiveness of the proposed design. This will also promote confidence amongst construction companies to apply geotextiles in their geotechnical designs (Koerner, 1984).

2.2 Properties of Geotextiles

Some of the properties of geotextiles, which are important in achieving an effective design are: tensile, flexure, puncture resistance, frictional resistance, hydraulic properties, permeability, compression resilience, and thermal, photo and chemical degradation; etc.

2.2.1 Mechanical Properties

Woven and nonwoven geotextiles are widely used, and they are generally anisotropic, hence both their uniaxial and biaxial deformations are studied. The mechanical properties of the nonwoven geotextiles are also dependent upon the manufacturing technique employed, for example needlepunched, hydroentanglement, thermal and chemical bonding, whereas, in the case of woven geotextiles, they vary according to the type of weave. For example, plain weave fabrics generally offer better tensile resistance than matt and twill woven fabrics. Nonwoven fabrics possess lower bending rigidity and have higher extensibility which make them suitable for certain applications, such as separation, where good mechanical properties are not required. On the other hand, woven geotextiles provide better resistance to tensile deformation and they are stiffer, and are therefore ideally suited for applications, such as reinforcement, where load-bearing capacity is required. The mechanical properties of the woven and nonwoven geotextiles are also dependent upon the characteristics of the fibres, intrinsic properties of the polymers and the structural architecture.

However, the tensile properties of geotextiles, measured on conventional tensile testing instruments, do not accurately simulate the actual conditions prevailing in their applications. For example, geotextiles confined with a soil layer undergo a different mode of deformation to that applied in the laboratory. The frictional resistance against the stationary soil has to be overcome by the applied tensile load. Some noteworthy attempts have been made to test the mechanical properties of geotextiles in simulated conditions, although, it is quite difficult to simulate the real conditions in the laboratory (Andrawes et al, 1984).

2.2.2 Puncture Resistance and Compressional Properties

In many applications, such as in road and railway, axisymmetric loading occurs rather than in-plane loading (Bergado et al, 2001). Under such loading conditions, nonwoven geotextiles improve the load-bearing capacity of soft grade soils. Therefore, puncture resistance is one of the important properties studied in certain laboratory tests, in which a concentrated load is applied normal to the plane of the pre-tensioned fabric. The resistance to puncture is dependent upon the magnitude of the distributed load and the extent of pre-tension in the specimen. The puncture resistance of geotextiles is also affected by the properties of the soil which, include shear strength, angularity, bluntness, softness etc.

Static and dynamic compressional forces are exerted on geotextiles when they are applied in road and railway applications. For example, dynamic compressional loading is exerted by a running vehicle. Nonwoven geotextiles are known to provide good compressional properties and resilience under cyclic loadings.

2.2.3 Frictional Properties

Geotextiles employed for reinforcement of soil particles, have good resistance to shear and compressional forces but are quite weak and susceptible to failure under tensile load. The geotextile, as reinforcement, allows effective transfer of most of the shear stresses from the soil to itself, by surface friction and remaining stress by interlocking with the surface frictional properties of the geotextile play an important role (Rawal et al, 2010).

2.2.4 Hydraulic and Permeability properties

As geotextiles are porous structures, they provide both in-plane transmissivity and cross-plane permeability, by allowing flow of the fluid medium through the pores or voids. The rate and amount of the fluid flow will depend upon the size and depth of pores, and their distributions. Therefore, the design of the pores in geotextiles needs special attention for those specific applications demanding specific functions, such as filtration, separation and drainage.

To determine the air or water permeability properties of geotextiles involves the measurement of the volumetric flow rate of air or water per unit cross-sectional area against the defined differential pressures. The measurement of air and water permeability is important depending upon the application of the geotextile. Air permeability is important when estimates of air or gas passing through, or collected in, the medium are required, for example in landfill sites. Water permeability is important in filtration and drainage applications. In-plane transmissivity of fluid is important in drainage applications.

2.2.5 Pore Size and Pore Size Distribution

Nonwoven geotextiles provide a unique fibrous network of interconnected pores, which play a key role in fluid transport. Complexity of pores, in a nonwoven geotextiles, is related to pore size, shape, geometry, pore volume, and to the smallest and largest pores and pore size distribution, which all influence the fluid flow through the medium. While woven fabrics provide reasonably well defined symmetric pores, nonwoven fabrics exhibit wide variability in this respect. Simple definition of porosity relates the total volume of the voids to the total volume of the material, expressed as a fractional ratio. Such simplification of porosity, however, does not take into account the structural characteristics of the material, hence cannot assist in characterizing the flow characteristics and liquid uptake. The surface pores differ in shape and size; also they are open or closed along the thickness of the material. Therefore, it is necessary to analyze the pore size in terms of pore size distribution, which is generally unimodal and bimodal for nonwoven and woven fabrics, respectively. Therefore, an appropriate distribution function needs to be fitted to experimentally measured pore dimensions in the geotextile structures. A number of different measurement methods, such as sieving (dry, wet and hydrodynamic), image analysis, mercury intrusion and liquid extrusion, are employed to estimate pore size distribution in nonwoven geotextiles, nevertheless, none of these methods is universally accepted (Bhatia et al, 1996).

2.2.6 Degradation

Geotextiles are subjected to a wide variety of environmental, chemical, heat and sunlight exposures during their use. For example, the chemical resistance of the geotextile needs to be considered for applications in municipal and hazardous waste landfills, reinforcement of slopes and subgrade soils. These geotextiles are exposed to alkaline and acidic solutions in municipal landfills due to wet food and liquid wastes. Geotextiles, made from polyester and polypropylene, are used in such landfill applications and a number of studies have shown that they are susceptible to degradation under alkaline and acidic conditions (Mathur et al, 1994). Geotextiles made from polyolefin are relatively stable, and are not much affected by chemicals. They are, however, susceptible to a loss in strength and increased brittleness when exposed to ultraviolet light, which is more profound at elevated temperatures.

This presentation will discuss various types of geotextiles, their production techniques and applications, as well as the opportunities that can be explored through research and development aimed at cross-cutting industry segments, particularly nonwoven industries supplying materials for geosynthetic applications.

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