Chapter

# Review of Sustainable Geosynthetic Development Trend with Environmental Adaptive and Eco-Environmental Performances Point of View

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## Abstract

Most of the geosynthetics contribute to the long-term stability of the soil structure, so products with little change in long-term performance are mainly used. To this end, demand for biodegradable products emphasizing planting and environmental compatibility is increasing. Sustainable geosynthetics can be categorized as "Usual Geosynthetics" and "Green Geosynthetics" on the basis of required performance, and it can be said that it is meaning to expand the use of geosynthetics in the fusion level. In here, "Usual Geosynthetics" refer to functional long-term maintenance and environmental adaptive products, and "Green Geosynthetics" refer to eco-environmental products that are decomposable geosynthetic fibers whose functions are extinguished after a required period of time. In this paper, we introduce sustainable geosynthetics, which are differentiated from raw materials to applicability.

**Keywords:** environmental compatibility, biodegradable, sustainable geosynthetics, usual geosynthetics, green geosynthetics, environmental adaptive, eco-environmental

## 1. Introduction

Terminology of Geosynthetics is that "a planar product manufactured from polymeric material used with soil, rock, earth, or other geotechnical engineering related material as an integral part of a man-made project, structure, or system." Their functions of geosynthetics are shown in **Figure 1**, and polymeric materials for geosynthetics are shown in **Figure 2** [1–3].

Actually, polymeric materials for geosynthetics have their unique properties, and various additives are mixed to have the suitable and various functions of geosynthetics, and the manufacturing process is also different for each product. **Figures 2** and **3** show abbreviations and abbreviated definitions and examples of typical geosynthetic products, respectively.

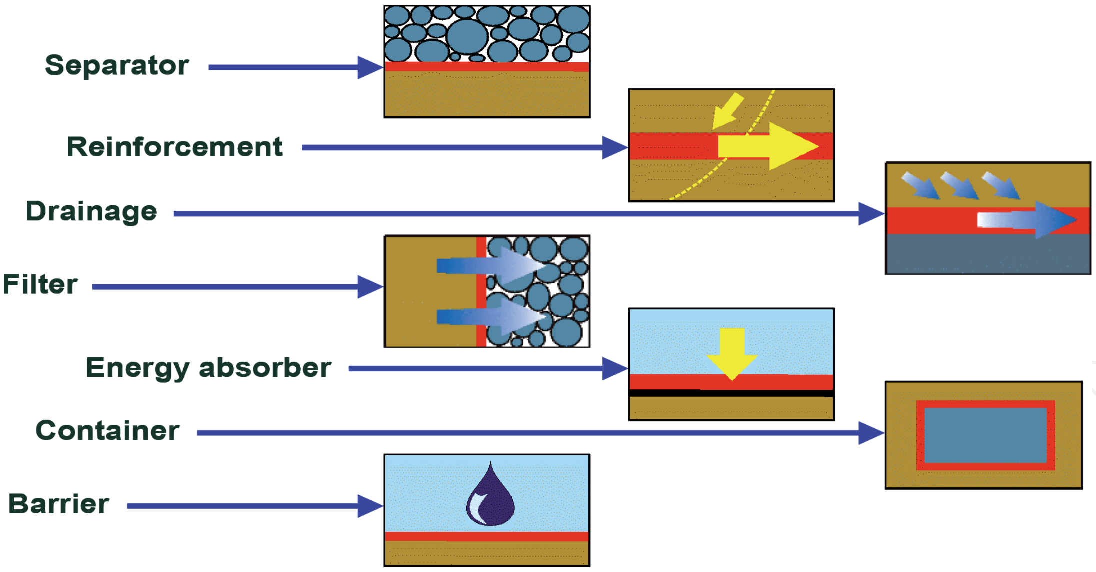

**Figure 1.**
*Functions of geosynthetics in soil structure.*

*Separation*
separating dissimilar materials so that both can function as originally intended
*Reinforcement*
providing tensile strength to soils or other materials
*Filtration*
allowing cross-plane flow, yet retaining upstream particles
*Drainage*
providing in-plane flow, yet retaining upstream particles
*Containment (or Barrier)*
preventing liquids, gases, or solids from becoming fugitive

**Figure 2.**
*Functions of geosynthetics for application.*

- Geotextiles (GT)
- Geogrids (GG)
- Geonets (GN)
- Geomembranes (GM)
- Geosynthetic Clay Liners (GCL)
- Geofoam (GF)
- Geocomposites (GC)

Geosynthetics - polymeric construction materials used in the ground
Geotextiles - permeable fabrics capable of multiple functions
Geogrids - interconnected sets of ribs used in reinforcement
Geonets - integrally joined sets of ribs used for drainage
Geomembranes - impermeable polymer liners used as a containment
Geosynthetic Clay Liners - bentonite layer between GTs on a GM used as a barrier in containment applications
Geocomposites - GSs laminated together or GSs used with soil

**Figure 3.**
*Abbreviations and abbreviated definitions of geosynthetics.*

## 2. Sustainable geosynthetics

Most of the geosynthetics contribute to the long-term stability of the soil structure, so that products with small changes in long-term performance are mainly used, while demand for biodegradable products emphasizing planting and environmental compatibility is also increasing (**Figures 3** and **4**).

Therefore, sustainable geosynthetics mentioned in this chapter are classified as "Usual Geosynthetics" and "Green Geosynthetics" based on required performance as shown in **Figure 5** [6, 7].

First, environmental adaptive geosynthetics, which we have previously described as "Usual Geosynthetics," have not changed much over the past 20 years but have created a paradigm of composite products using extreme strength fibers with the keyword of diversification. The environmentally adaptable geosynthetics can be introduced as "Usual Geosynthetics," which are used to reinforce the ground structure, and the initial strength retention rate should be within the given range during the service life.

In other words, usual geosynthetics are a product that requires a high resistance to instantaneous loads from the outside and also requires a hybrid function that converges to the reinforcement, protection, and blocking functions that are the basic functions of geotextiles. Since natural fibers have the advantage of being eco-friendly

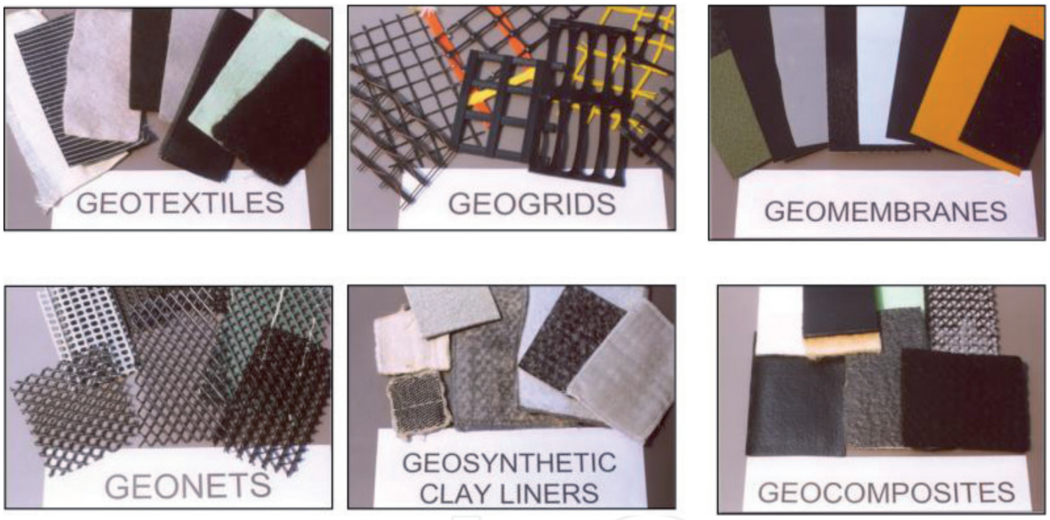

**Figure 4.**
*Examples of typical geosynthetic products.*

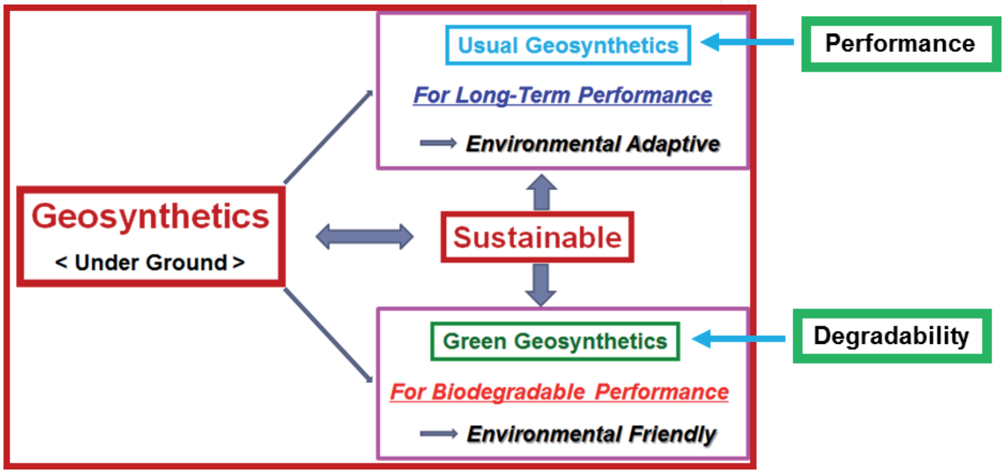

**Figure 5.**
*Schematic diagram of "Sustainable Geosynthetics".*

materials, the utility of geotextile as a raw material has begun to be reemerged in recent years such as various types of cotton, jute, coir, and straw. However, since it is not used much and cannot be mass-produced compared to synthetic fibers, it has difficulties in creating demand. Some of them use natural geotextiles as slope stabilization, erosion prevention, and drainage, but here is no big change [4].

On the other hand, polyolefin (polyolefin) and polyester (polyolefin) are the most widely used synthetic polymer materials. Polyurethane, glass, and carbon polymers are very limited. Since the polymer materials used in the manufacture of geosynthetic products are often used in large quantities by low cost. In general, manufacturing high-performance geosynthetics increases the manufacturing cost, which is economically expensive. In other words, if the performance is the same, a product with a lower manufacturing cost is economically advantageous. Considering this, geosynthetics using recycled polymer materials may be considered, but disadvantages of performance decrease compared to geosynthetics using virgin polymers rather than recycling becomes a problem. Considering the environmental aspects, it is preferable to use recycled polymer materials, but the additional cost of recycling is not recommended in terms of economic performance.

High-performance hybrid polymer materials are being used as convergence geosynthetic products are required to protect, repair, and repair the ground structure from natural disasters such as earthquakes, tsunamis, and typhoons. These convergence geosynthetic products play a pivotal role in improving the stability of geotechnical structures and expanding their applications. Carbon fibers, aramid fibers, and liquid crystal polymer fibers are being used as new materials. In addition, test methods and construction techniques related to these new materials are being developed to expand the performance of these convergence geosynthetic products.

Second, "Green Geosynthetics" refer to products that have sustainable degradable geosynthetic fiber and environmental pollution prevention and restoration functions that do not mean long-term implementation of initial performance in terms of environmental friendliness.

For the slope stabilization/protection field requiring eco-environmental properties, mesh type geocell using biodegradable resin is applied to slope vegetation, river maintenance, eco-slope composition, garden-based layer, landfill slope, and waterproof protection. This reflects the demand for eco-environmental geosynthetics and means that there is a growing need to expand biodegradable geosynthetics to civil/environmental fields. In addition, polypropylene staple fiber products have been developed in the geosynthetics and web structures to emphasize the slope reinforcement function.

In the case of fiber, "biodegradability" means decomposition by microorganisms or bacteria in the soil, which is a geotechnical structure, and the initial performance gradually decreases during the service period [5].

In order to recover the contaminated environment and to manufacture "Green Geosynthetics," a biodegradable resin should be used as a raw material, and it is differentiated from geo-fiber, which cannot be decomposed after construction. Also, when used as a filter, manufacturing of geotextiles in the form of nanofibers helps improve filtration efficiency.

## 3. Hybrid geosynthetics

### 3.1 For water permeable and reinforced functions

In the case of using the geosynthetics alone, it is true that the application field is extremely limited due to the limitation of its function. For this reason, hybrid geotextiles suitable for specific functions and environments have been developed, and their usage is also increasing faster than in any field of civil engineering synthetic materials. In other words, a product that combines geogrid and geotext styles, which are widely used in landfills, reinforced earth retaining walls, roads, and soft ground reinforcement, has been developed.

This means geogrid's reinforcement function and geotextile's permeability function, and geogrid and geotextile are bonded through thermal and ultrasonic welding. In this product, the tensile strength and puncture resistance are increased, the effective hole size and the vertical permeability are reduced, but the tear strength is not greatly influenced by the change in weight. In addition, it is expected that when the actual construction is performed from the tensile strain and the creep strain of the geogrid, not only the reinforcing function but also the partial geotextile protection effect can be obtained.

### 3.2 For protection and water barrier

The geomembrane has a smooth sheet shape, so it has low frictional force with the soil and much surface damage is caused by sharp objects such as gravel, concrete slabs, and tree roots in the construction process.

In addition, when the geomembrane used as the cargo material in the landfill is slid at the interface with the soil or other geosynthetics, or when the surface is damaged, it causes problems in the stability of the landfill system during or after the landfill is completed and may be affected by the leachate generated when the waste is decomposed.

Therefore, tensile, tear, rupture, and puncture strength are increased when the geomembrane and geotextile composite are manufactured, and the internal friction angle with respect to the contact soil is increased to improve the shear characteristics. And the stability of the geomembrane leachate is improved by the protection effect of the geotextile.

This phenomenon is due to the fact that the difference in strength between two directions due to stretching, which is generally seen in the geomembrane, is complemented by the thermal fusion bonding, and the resistance to the tensile force is increased due to the reinforcing effect of the geotextile and the geomembrane bonding part.

### 3.3 For separation, filtration, and reinforcement

Geotextile surface smoothness can be improved to improve separation function and reinforcement function of reinforcing geotextile, and AOS (Apparent Opening Size) of geotextiles by differential design can improve filtration function (**Figure 6**).

These products have the overall performance (chemical stability, high tensile properties, permeability, etc.) as geomembrane protection material in the landfill construction where frequent damage of the aeration sheet is caused by the aggregate applied to the leachate drainage layer and the working vehicle on the top can be used as a composite product.

### 3.4 For auxiliary water barrier function

As shown in **Figure 6**, hybrid products such as GCL, which are used as auxiliary water barrier materials, have been developed, such as improvement of swelling property, prevention of loss, and improvement of freezing and thawing properties. In addition, bentonite modification and the like are progressing with the aim of improving the swelling property in salt water, and the interest in the product for preventing environmental pollution is also increasing.

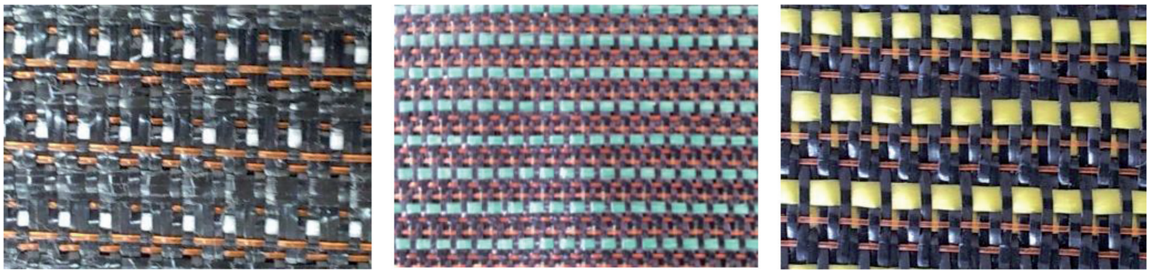

**Figure 6.**
*Geotextiles for [separation/filtration/reinforcement] functions improvement.*

As a part of development of hybrid geosynthetic clay liners, GCL applies (1) multi-layered swelling enhanced bentonite, (2) bentonite surface strengthening performance, and (3) bentonite for blocking and removing harmful components. Bentonite reforming and hybrid GCL development give the differentiated performance to the GCL products such as this way.

### 3.5 For multi-axial geocomposite

Geocomposite manufacturing technology and products were developed for the purpose of reinforcement function by developing not biaxial but multi-axial curved knitting materials, which can enhance the ground reinforcement function by applying multi-axial curved knitting technology.

In addition, a smart monitoring high performance multi-axial geocomposite is being developed in order to monitor the damage of the geocomposite due to stress concentration by appropriately embedding the optical fiber sensor in the multi-axial geocomposite as shown in **Figure 7**.

### 3.6 For reflective crack protection

The life of the pavement is affected by rutting caused by the load of the vehicle and the driving load of the vehicle. In particular, due to differential settlement by rutting, the reflective crack is generated, and the road fracture proceeds due to the propagation of the reflective crack. Reflective crack is also the main cause of differential settlement due to plastic deformation, and it also has a great influence on road stability, causing social problems due to increased casualties due to vehicle accidents.

Therefore, in order to improve the durability and stability of the pavement by reflective cracks and to improve the driving performance of the vehicle, it is necessary to use geosynthetics that can suppress the reflective cracks.

**Figure 7.**
*Multi-axial geocomposites by optical sensor application technology.*

**Figure 8.**
*Anti-reflective crack geosynthetics for road construction.*

Taking this into consideration, reinforcement of asphalt and concrete roads using geosynthetics has a great effect on suppressing reflective crack and differential settlement and has the advantage of blocking water penetration by reflective crack.

From the above view, it is necessary to develop geosynthetics that can improve the stability of roads by improving the resistance to fatigue loading of road structures by rutting and differential settlement (**Figure 8**).

## 4. Nanomaterial application to geosynthetics

**Figure 9** shows various aspects of nanofiber manufacturing technology and production where it is seen that mass production of nanofibers is possible by modified electro spinning. Electro spinning is the general method used to manufacture nanofibers, which is similar to the meltblown method, but the current problem is to increase mass production.

Regular size (~ 1 denier) fibers are used as 2500–6000 denier to implement the function of geosynthetic products (e.g., separation /reinforcement/drainage/filtration/protection, etc.). However, if micros and nanofibers are used to make geosynthetic products for separation and filtration, more fibers can be integrated in a given space, and separation and filtration will be improved than with regular size fibers. **Figure 10** shows the fiber manufacturing method with fiber length, and micro and nanofibers, which are smaller in fiber thickness, are selected for fibrillation process that is different from the general spinning process. Nanofibers, in particular, have not been significantly out of the range of electrospinning.

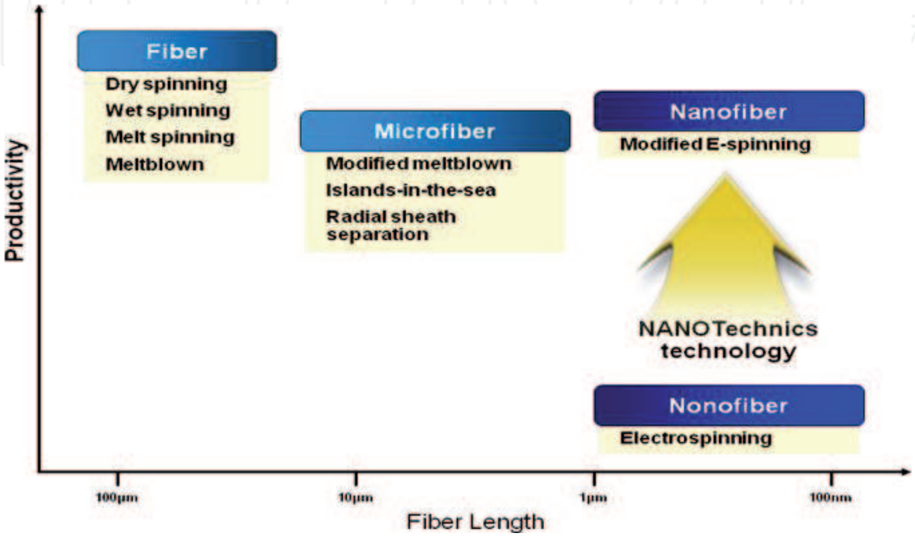

**Figure 9.**
*Fiber manufacturing technology and productivity.*

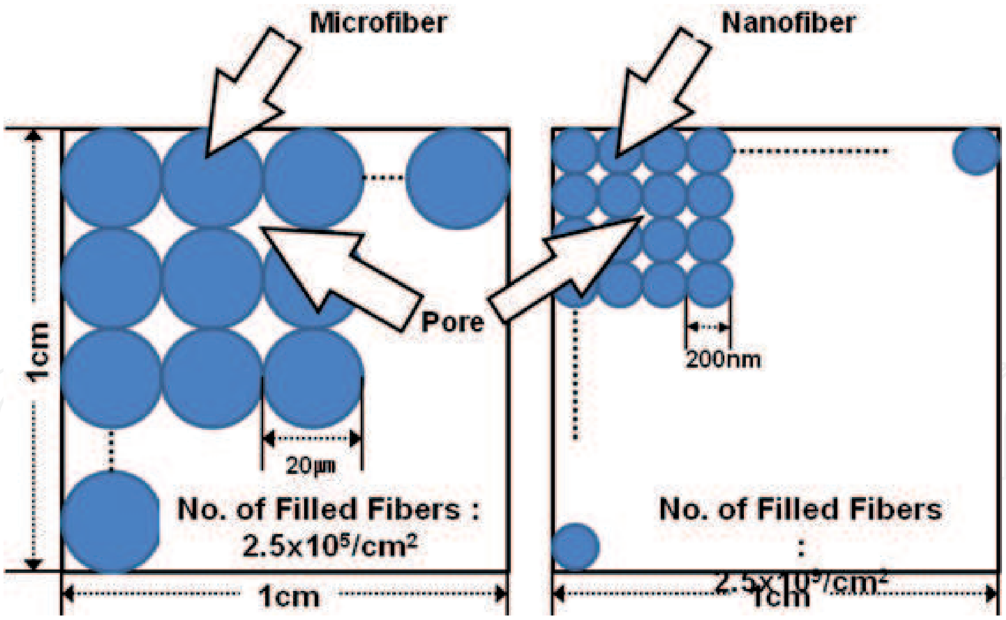

**Figure 10.**
*Fiber filling between microfiber and nanofiber per unit area for geosynthetics.*

One of the methods for improving the filtration function is to increase the pore size per unit area. Conversely, increasing the number of filled fibers per unit area in order to improve the adsorption performance reduces the pore size due to the increase in specific surface area. Therefore, the fine particles cannot pass through the pores made of nanofibers, thereby improving the filtration efficiency. It can be seen that liquid and gas filters using micro and nanofibers can be used to adsorb fine particles and heavy metal ions in water and air media (**Figure 11**).

**Figure 12** is a schematic diagram showing the relationship between adsorption and desorption of fine particles in the direction of pressure. Higher particle densities or adsorption rates are required to optimize these filter performances, and micro and nanofibers can be used to maximize the capture and removal efficiency of particles. **Figure 13** shows the fiber density per unit area by fiber length and thickness and the filtration area per fiber weight with the filter manufacturing process. HMT and expanded PTFE (polytetrafluoroethylene) fibers have a relatively higher fiber density per unit area than spunbonded, flashspun, and meltblown

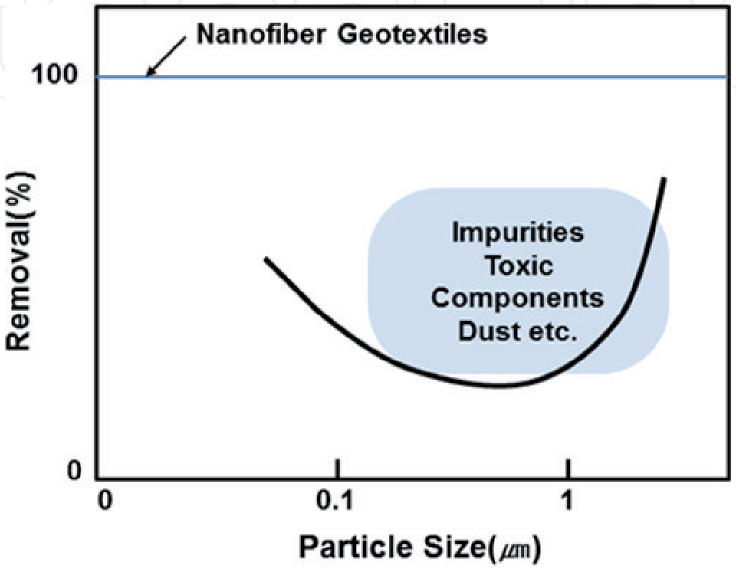

**Figure 11.**
*Effect of using a nanofiber geotextile filter.*

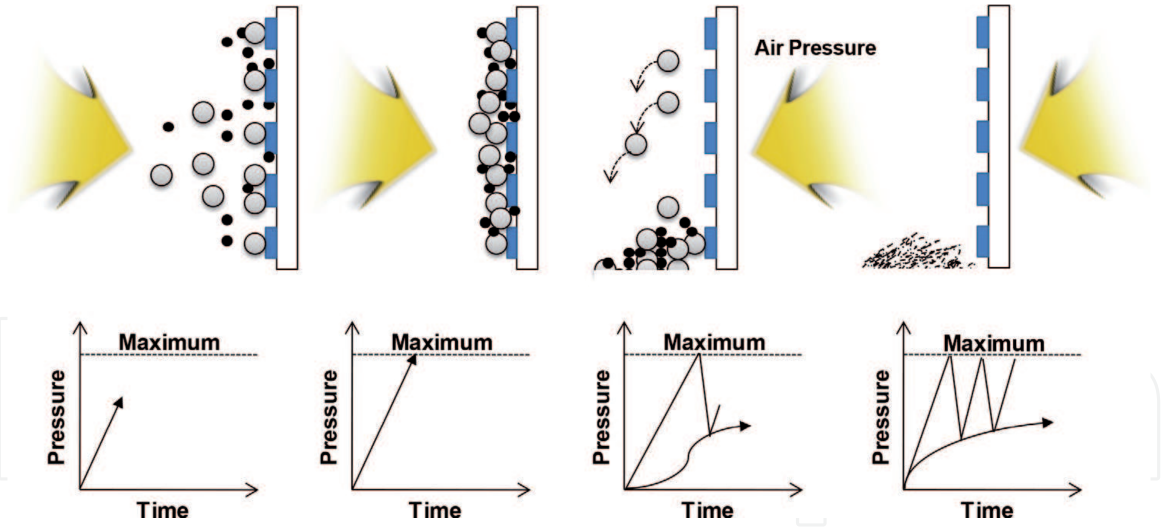

**Figure 12.**
*Maintenance of filtration efficiency for nanofiber filters.*

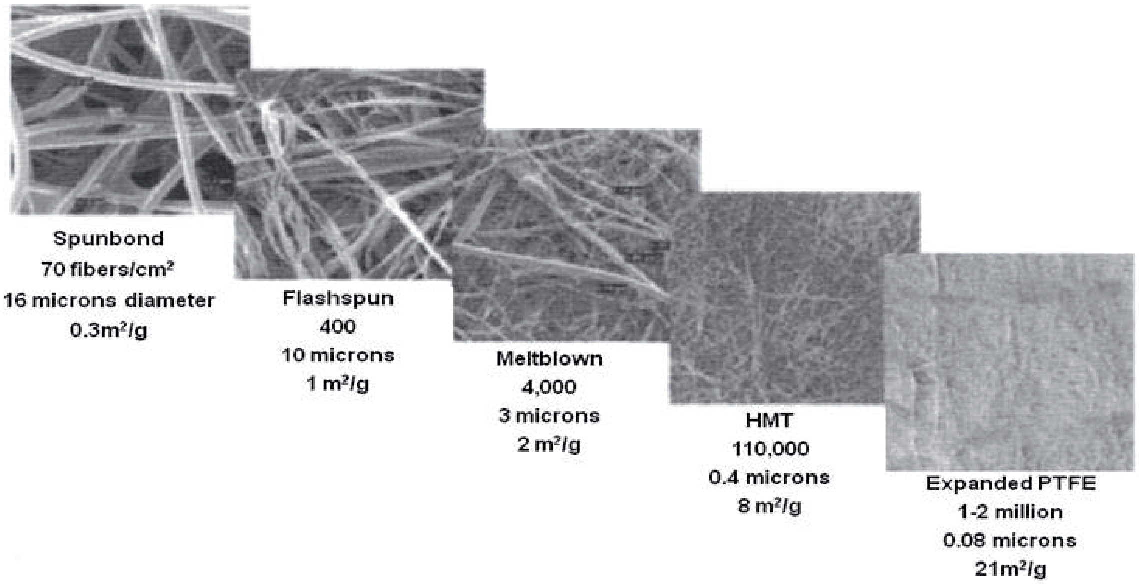

**Figure 13.**
*Comparison of fiber diameter and surface area using nanofiber and other fibers.*

fibers. Therefore, it can be seen that the filter performance by the optimization of the specific surface area is excellent. **Figure 14** shows the particle distribution area that can be removed using micro and nanofiber filters.

From the above, when applying geosynthetic products made of micro and nanofibers to the environmental field, considering the theoretical basis and validity, considering the limitation and economic disadvantage of fiber manufacturing process, development of differentiated technology and application should be preceded.

In order to remove the heavy metals and toxic substances contained in contaminated soil, a nonwoven geotextile is used, which is a mixture of nanofiber clay with polyester fiber (**Figure 15**).

The specifications of nonwoven geotextiles with 2–3% yellow clay particles and the composition of yellow clay particles are shown in **Tables 1** and **2**, respectively.

Clogging in nonwoven geotextiles means apparent opening size (AOS), which represents the size of the voids between the fibers that make up the nonwoven fabric, and this value depends on the distribution and continuity of the fibers that make up the nonwoven geotextiles. In general, the AOS value could be controlled in

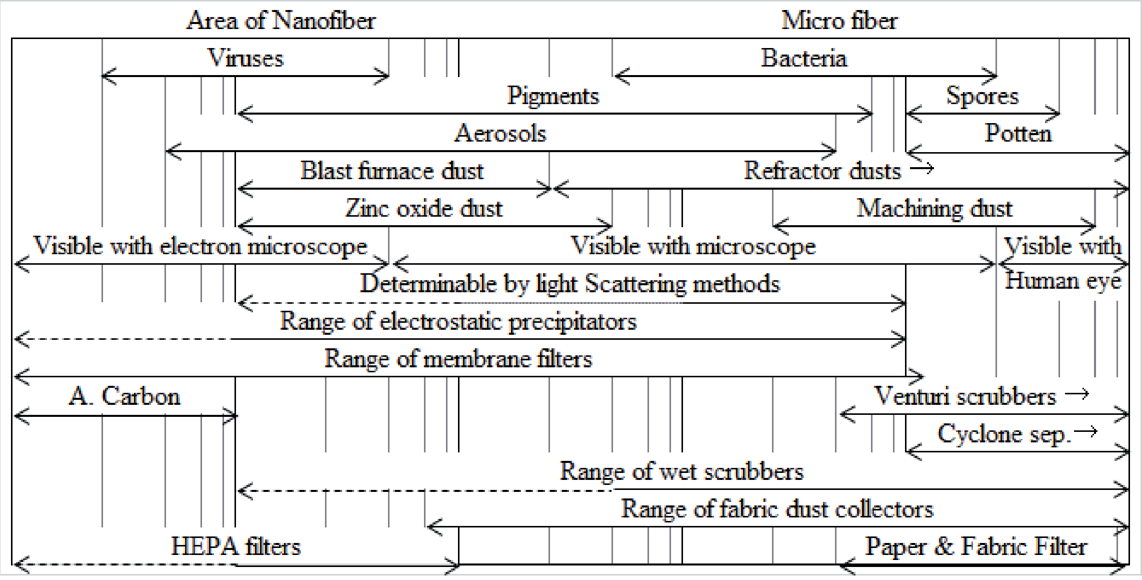

**Figure 14.**
*Relationship between separation fields and membranes using nanotechnology.*

**Figure 15.**
*Clay added geotextile to improve adsorption efficiency.*

| **Composition Nonwoven geotextiles** | | **Weight (g/m$^2$)** | **Yellow clay content (%)** | **Raw fiber** |
|---|---|---|---|---|
| With yellow clay added geotextiles | FGT-1 | 272 | 2 ~ 3% | Polyester Fibers (6 denier Filament) |
| | FGT-2 | 463 | | |
| | FGT-3 | 784 | | |
| | FGT-4 | 1514 | | |
| Without yellow clay geotextiles | GT-1 | 284 | None | |
| | GT-2 | 480 | | |
| | GT-3 | 756 | | |
| | GT-4 | 1546 | | |

**Table 1.**
*Specifications two types of polyester geotextiles.*

| Component | Yellow Clay | $SiO_2$ | $Al_2O_3$ | $Fe_2O_3$ | $TiO_2$ | CaO | MgO | $Na_2O$ | $K_2O$ |
|---|---|---|---|---|---|---|---|---|---|
| Amount | 97.54 | 1.80 | 0.07 | 0.11 | 0.13 | 0.01 | 0.01 | 0.02 | 0.01 |

**Table 2.**
*Components of yellow clay particles.*

the nonwoven geotextiles manufacturing process and the smaller the AOS value, the lower the permeability.

**Figure 16** shows the AOS values before and after burial of nonwoven geotextiles used in landfills. Nonwoven geotextiles (FGT) added with yellow clay particles showed smaller AOS values than nonwoven geotextiles without yellow clay particles. This is thought to be due to the fact that the pores of the FGT of with yellow clay particles are smaller than the GT of without yellow clay particles.

As same as shown in **Figure 16**, analytical result of AOS value, heavy metals, or harmful components contained in the leachate solution may be more easily removed by adsorption using FGT than GT (**Figure 17**).

**Figure 17** shows the permittivities between FGT and GT before/after burial in the waste landfill site. As same as shown in **Figure 16**, FGTs showed smaller permittivity than GT due to the clogging effects by smaller AOS values.

**Figure 18** shows the adsorption efficiency of the heavy metal component of the nonwoven geotextile of with yellow clay particles, this value is by ICP analysis expressed as a percentage. This is also due to the AOS value of with/without yellow clay as same as shown in **Figure 16**.

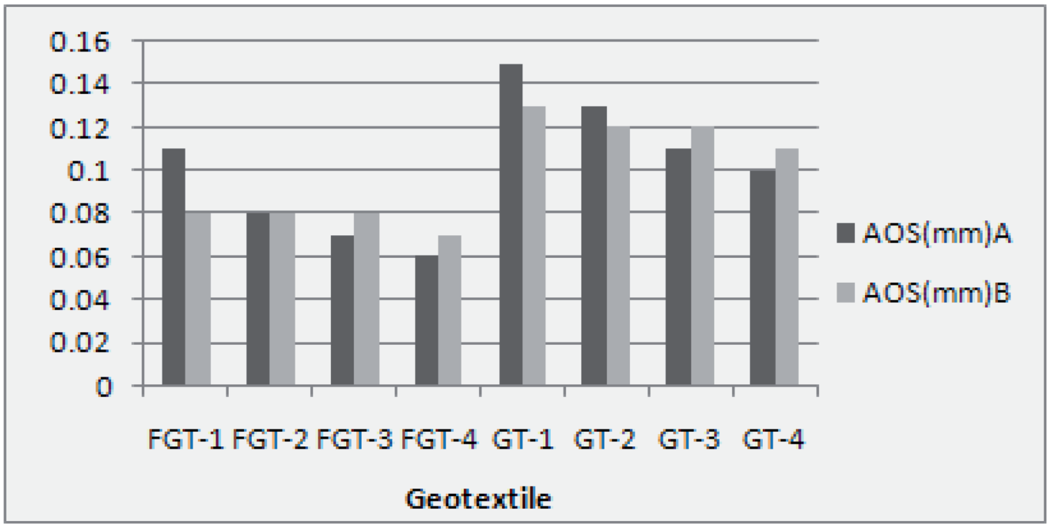

**Figure 16.**
*AOS of with/without yellow clay nonwoven geotextiles before/after immersion. (Where A, B mean before and after immersion, respectively).*

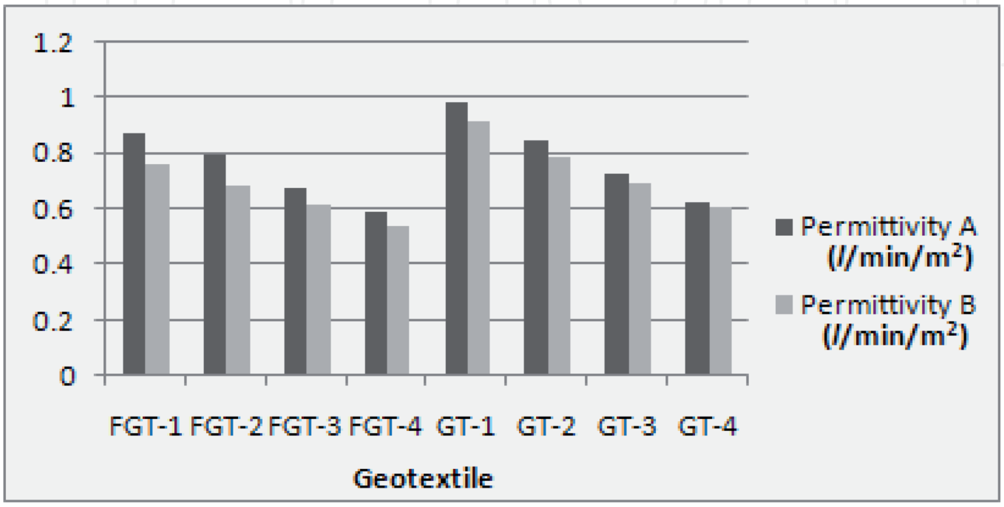

**Figure 17.**
*Permittivity of with/without yellow clay nonwoven geotextiles before/after immersion. (Where A, B mean before and after immersion, respectively.*

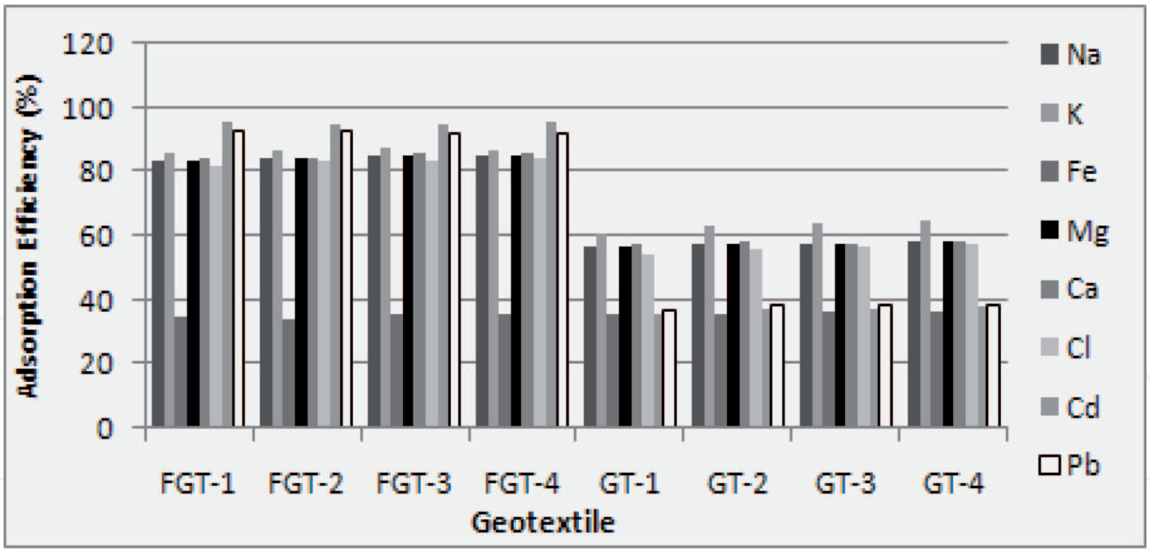

**Figure 18.**
*Adsorption efficiency of with/without yellow clay nonwoven geotextiles.*

In the future, if micro and nanofibers are used to manufacture nonwoven geotextiles, the development of technology to control the AOS distribution is expected to create new demands in soil removal, prevention, and restoration.

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