Geosynthetics: An overview

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Abstract

The paper provides an overview of history of geosynthetics, raw material, manufacturing, types, functions and applications. Usage of geosynthetics material goes way back when natural fibers were used as soil reinforcement in ancient structures. Different types of geosynthetic materials such as geotextiles, geomembranes, geogrids, geocomposites etc. are used in various functions of geotechnical and landfill engineering. These materials perform various functions of separation, filtration, drainage etc. The growth of geosynthetic market in the next few years and various developments taking place in this field is also summarized in this paper.

1.0 Introduction

Geosynthetics is an emerging field offering various applications globally. It refers to the planar products synthesized from polymeric materials used with geo materials like soil, earth, sand etc. for applications like transportation, hydraulics, roads, embankment, retaining walls, canals, erosion control, waste landfill, revetments etc. Geosynthetics have been increasingly used in geotechnical, environmental engineering and civil engineering replacing the use of conventional, restricted or expensive construction materials. These materials have long term durability, high strength and stiffness.

2.0 History of Geosynthetics

History of geosynthetics dates back to the time when linen, bamboo, reeds, timber, grass mats and other natural elements were found during excavation of ancient structures. Geotextiles made with natural fibers or vegetation was usually reinforced with soil to improve road stability.

The first use of woven fabrics as filter fabrics or construction fabrics was in 1950s and 1960s in coastal and hydraulic engineering in the Netherlands, Germany, and the United States. Carthage Mills' president along with the University of Florida developed a woven synthetic filter fabric to protect erosion from Florida storm in 1957.R.J.Barrettworkedon geotextiles for erosion control. He was recognized as a "father of filter fabrics". The Dutch used geotextiles in Delta Works flood protection scheme in the early 1960s which was honoured as one of the Seven Wonders of the Modern World by The American Society of Civil Engineers (ASCE). Since then in 1970s, there was emerging use of nonwoven fabrics in several European countries and woven fabrics in the United States. Many smaller textile companies like TenCate, Carthage-Mills and large chemical companies like ICI, Rhone-Poulenc, Enka/AKZO in Europe and DuPont, Phillips, in the United States drives this early technology. Carthage Mills and USACE participated in the construction of a full-scale embankment test section at Pinto Pass in Mobile, Alabama by which the first effective design criteria and construction techniques for "fabric-reinforced embankments on extremely soft soils" was developed [1,2].

The terms "geotextile" and "geosynthetics" were first coined by Dr. JP Giroud in a seminal paper and presentation at the First International Conference on Geosynthetics (1 ICG) in Paris in 1977 during his presentation the Valcros Dam in France. His early 1970s work, included the first use of a double-liner system, geotextile cushion with a geomembrane, and a geotextile for filtration and internal integrity of a dam embankment [1]. Prof. Heerten along with NAUE manufacturer in Germany worked for innovations in needle punched nonwoven geotextiles for advancement in geosynthetic clay liner materials [1,3].

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3.0 Raw Material for Geosynthetics

The selection of geosynthetic raw material depends on performance required in the field and its cost. On the basis of material used for manufacturing, geosynthetics is broadly classified into two

3.1 Usual Geosynthetics

These materials are adaptive to environment and provide long term functions such as high resistance to instantaneous loads, high initial strength retention etc. These are mainly produced from synthetic polymers [4].

3.2 Green Geosynthetics

These materials are made of eco-environmental biodegradable polymeric resins or natural materials that can degrade after service period and causes no harm to the soil and environment. These materials maintain their performance such as durability, design strength, hydraulic property etc. throughout the service period [4].

So, different fibres and polymers from both natural as well as synthetic category are used in geosynthetics for various applications.

3.3 Natural fibers

Earlier, natural fibers in fiber, yarn and knit form were used in geosynthetic products. With the development of non woven and woven type products, demand for natural geosynthetic products increased. Due to its quick biodegradability and small scale production it couldn't be used much. However, advantage of being eco-friendly materials, the utility of geosynthetic products in civil engineering as slope stabilization, erosion control, drainage, etc has recently begun to reappear. These materials are used in the form of paper strips, jute nets, wood shavings or wool mulch [5,6].

The raw materials of the products include cotton, jute, coir, straw, ramie, bamboo, coconut etc. Ramie possesses highest tenacity among all plant fibres. Jute has the ability to mix with the soil and serve as a nutrient for vegetation. Jute geotextile could be manufactured with specific properties treatment and blending. Its use as prevention of topsoil erosion and cracking is quite good. Jute geotextiles after degradation forms lignomass which enhances vegetative growth, soil organic content, fertility and stability of soil [5].

3.4 Synthetic polymers

The main synthetic polymers widely used as the raw material for geosynthetics are as follows

3.4.1. Polypropylene (PP)

It is one of the most widely used polymers for geosynthetic applications because of its low cost, acceptable tensile properties, and chemical inertness. Due to its low density it has extremely low cost per volume. The main disadvantage of polypropylene is its poor sensitivity to UV. In addition, at high temperature, its performance is easy to deteriorate, demonstrating poor creep characteristics due to low glass transition temperature [5].

3.4.2 Polyesters (PET)

The polymer in fiber form has high strength, modulus, creep resistance and general chemical inertness due to which it is more suitable for geotextiles. It possesses high resistance to ultraviolet radiations. Due to its high melting point, it can be used at high temperature. However, polyester can hydrolyse at pH above 10 [5].

3.4.3 Polyethylene (PE)

These polymers are mainly used in making geomembranes. Based on strength requirement, following three main groups of polyethylene are used, i.e, Low density polyethylene (LDPE, density 9.2-9.3 g/cc), Linear low density polyethylene (LLDPE, density 9.20-9.45 g/cc) and High density polyethylene (HDPE, density 9.40- 9.6 g/cc)

3.4.4 Polyamides (PA)

Nylon 6 and Nylon 6,6 are rarely used in geosynthetic applications. They have more strength but less modulus than polypropylene and polyester. They are also prone to hydrolysis.

3.4.5 Polyvinyl chloride (PVC)

Polyvinyl chloride is a hard plastic material. Flexible material can be made with the addition of plasticizers which is mainly used in geo membranes and thermo plastic coating materials.

3.4.6 Polystyrene (PS)

It is a light weight material of low density, mainly used in making of geofoams.

3.4.7 Ethylene copolymer Bitumen (ECB)

Ethylenecopolymer bitumen membrane has been used in civil engineering works as sealing materials.

3.4.8 Chlorinated Polyethylene (CPE)

Sealing membranes based on chlorinated poly ethylene are generally manufactured from CPE mixed with PVC or sometimes PE.

Additives such as antioxidant, UV absorbers, thermal stabilizers, flame retardents, antibacterial agents etc are generally added to enhance the performance of geosynthetics. Carbon black is mainly added for long term UV resistance and high strength.

Table 1 shows the types of polymers and their formulations for use in geosynthetics.

Table 1 : Type of polymers and their formulations

Type	Resin(%)	Plasticizer (%)	Fillers (%)	Carbon Black (%)	Additives (%)
Polypropylene	85-98	0	0	2-3	0.25-1
Polyester	98-99	0	0-10	0.5-1	2-5
Polyethylene	95-98	0	0	2-3	0.25-1
Polyvinyl Chloride	50-70	25-35	0-10	2-5	2-5
Polyamide	98-99	0	0	0.5-1	0.5-1
Polystyrene	98-99	0	0	0	1-2

4.0 Types of Geosynthetics

Fig 1 shows various types of geosynthetic material which are described as follows

4.1 Geotextiles

Geotextiles form one of the largest groups of geosynthetics. These are woven, non woven or knittedtextiles consisting of natural or synthetic fibers. These are flexible and permeable in nature.

4.2 Geomembranes

Geomembranes are the other largest group of geosynthetics. These are impervious sheets of polymer mainly used as fluid barriers. These are mainly made up of PVC and HDPE.

4.3 Geogrids

Geogrids represent a rapidly growing segment within geosynthetics. These are planar polymeric structures in grid form [7]. Cross over points is called junctions. Size of the aperture between individual ribs in the transverse and longitudinal directions varies as per the requirement. These are mainly used as a reinforcement material as it can interlock with soil or other earth material by its aperture. There are mainly three types of geogrids, uniaxial, biaxial and triaxial. In uniaxial geogrids, materials are stretched in one direction making it highly oriented in one direction having high strength in one direction only. In biaxial geogrids, materials are stretched in longitudinal as well as in transverse direction having tensile properties in both directions. Triaxial geogrids are triangular structure having multidimensional property. These materials have enhanced level of in-plane stiffness.

4.4 Geocomposites

Geocomposites are formed by the combination of geotextiles, geogrids, geonets or geomembranes for improved structures and enhanced functions.

4.5 Geonets/Geospacers

Geonets are net like structures similar to geogrids but flexible and thinner than that. In it, parallel sets of polymeric ribs are at acute angles to one another. These are also known as Geospacers. There are three types of geonets, biplanar, triplanar and box geonets. Biplanar geonets consists of two sets of intersecting ribs at different angles and spacing of different sizes and shapes. Triplanar geonets have parallel central ribs with smaller sets of ribs above and beneath mainly for geometric stability. Box geonets structures have either box shaped channels or protruding columns from an underlying support network.

4.6 Geosynthetic clay liners

Geosynthetic clay liners are geocomposites formed by sandwiching bentonite clay between two geotextiles or bonded to a geomembranes. Bentonite is clay that swells after absorbing water.

4.7 Prefabricated Vertical Drains (PVDs)

It is also a geocomposite consisting of plastic core and surrounded by non woven. These are held vertically in soils for drainage. Plastic core forms a channel for water movement, while outer geotextile fabric helps in filtation.

4.8 Geocells

Geocells are three dimensional honeycomb structure made by expanding parallel layers of welded polymeric strips. These are textured or perforated cellular mattress in which soil can be filled. Thus the movement of the soil confines to the cell of the structure, thereby known as Cellular Confinement Systems. These structures help in distributing loads over a wider area.

4.9 Geofoam

Geofoam is a light weight, block like polymeric material prepared by processing polystyrene into foam consisting of closed cells filled with air or gases.

4.10 Geocuspates

Geocuspates are used to provide a void space for the passage of either a liquid or a gas commonly used as a component in a Geocomposite. It is used in conjunction with a geotextile filter which helps in maintaining the void space. 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).

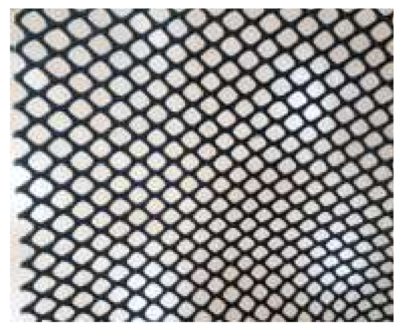
		
Woven Geotextile	Non Woven Geotextile	Geomembrane
		
Geogrid	Geocomposite	Geonet
		
PVDs	Geocell	Geocuspates

Fig 1 Different types of Geosynthetics

5.0 Manufacturing Process of Geosynthetics

5.1. Extrusion

During extrusion process, polymer chips in granular form and additives are fed to the hopper, which passes through the extruder. In extruder, polymer melts at high temp and mixes with additives. Molten polymer is then passed through a spinneret for yarn formation for geotextile materials or through die of desired cross section for making sheet for membranes or grids. Materials are often drawn to impart strength through molecular orientation.

5.2. Manufacturing of Geotextiles

5.2.1. Non woven geotextiles

A nonwoven geotextile is made of directionally or randomly orientated fibres. Fibers are laid down in the form of a web with two principal methods. First one is dry laid or carded webs in which staple fibres are carded and then cross lapped (folded) for web formation and other is polymer laid or spunlaid webs in which fibers from extrusion spinning process are directly collected to form a web. Laid fibers are then mechanically or thermally bonded. In mechanical bonding, fibre entanglement via water jets, needle punching and stitch-bonding techniques are used. In thermal bonding, a thermoplastic component in the form of a homofil fibre, powder, film, or as a sheath part of a bi-component fibre is present in the web which melts forms the bonding region with the application of heat. Finishing of fabric is done by thermal calendaring process in which the nonwoven web is passed continuously between two heated cylinders under pressure.

5.2.2. Woven Geotextiles

In it, two parallel set of materials such as film tape, extruded flat tape, multifilament yarn, monofliament yarn, tape yarn are interlaced at right angle to form a structure. The properties of the geotextile will depend upon the material used and weave pattern.

5.2.3 Knitted Geotextiles

In it, a fabric is formed by a series of interlocking loops of yarn by warp or weft knitted technique.

5.3. Manufacturing of Geogrids

5.3.1. Integral Junction Geogrids

In it, apertures are created by making holes in the extruded sheet of polymers. Sheets are then drawn either in one or multi direction to form a high strength and stiff structure. There are generally two methods for creating holes in the sheet, one in which flat sheet is punched and other is made on circular die with a piston creating the holes.

5.3.2. Fused Junction Geogrids

In it, strips of high tenacity polyester coated with polypropylene for durability are used. The machine and cross machine elements are bonded together by sonic welding.

5.3.3. Woven Junction Geogrids

In it, strips of high tenacity polyester is coated with polypropylene or PVC for protection against environmental exposure. The machine and cross machine elements are interweaved at multiple levels.

5.4. Manufacturing of Geonets

Geonets are manufactured by using a counter rotating die which consists of an inner circular die 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 between 60° to 80° forming diamond shaped aperture and junctions. The net is extruded as a tube which is cut and drawn to create a flat rolled product.

5.5. Manufacturing of Geomembranes

Geomembranes are made of extruded polymer sheets either flat or as a tube that is split in the machine direction. These sheets are then processed by calendaring and/or spread coating. However, they can also be made by impregnating a geotextile with asphalt, or as multi-layer bitumen composites. The raw material can be a plastic (e.g. PVC, HDPE, LLDPE), a rubber (e.g. EPDM, EVA) or a combination of the two.

5.6. Manufacturing of Geocuspates

In it, an extruded sheet is formed into either cups or studs, with a variety of heights and spacing which determine the size and area of the void. There are two methods of forming voids. First one is using vacuum in which a semi molten sheet of polymer is stretched and forced against the mould by vacuum and the other is roller forming in which a semi molten sheet of polymer is passed through two roller having mould design.

5.7. Manufacturing of GCL's

In it, a uniform layer of sodium bentonite is bonded with upper and lower layer of geotextile by an inert adhesive, stitching or by the needle punching process. There should be no pockets or voids that could conduct liquids.

5.8. Manufacturing of Geocomposites

There are generally three methods for combining materials to produce a geocomposite.

5.8.1. Adhesive Bonding

In it, an adhesive is applied to materials by spray, bath or roller to bond them together. The short term and long term properties of the finished composite is determined by the quality of adhesive used.

5.8.2 Heat Lamination

In it, a thin layer of molten polymer is pressed against the other material and pressed to form a composite.

5.8.3 Stitching

In it, components are stitched together using high strength yarns. This is an effective way of combining materials. However it is a time consuming process.

5.8.4 Welding

In it, welding of two materials is done by high frequency ultrasonic acoustic vibrations under pressure. The strength of welded section can be close to the strength of material if done effectively.

6.0 Functions of Geosynthetics

6.1 Separation

Geosynthetic material can separate different type two kinds of materials allow the free passage of liquids/gasses. Commonly used in between subbase/subgrade and around drainage materials.

6.2 Filteration

Geosynthetic materials which are permeable in nature can allow water and liquids to pass though while restraining soil particles when flow is perpendicular to the material. This helps in prevention of soil, sand and other small particles.

6.3 Drainage

Fluids and gases flows along the plane of geosynthetic material acts as a drainage channel. Geotextile material can collect water and discharge slowly along the geotextile.

6.4 Reinforcement

The reinforcement function of geosynthetic material is most commonly used in geotechnical engineering. Tensile modulus, tensile strength, and surface friction are the three important properties of material used in geosynthetic application. It forms a reinforced composite soil when placed in the soil as a reinforcing material. The strength and deformation performance of the reinforced composite soils are improved and enable steep slopes and soil structures to be constructed over weak and variables soils. It also prevents soil erosion.

6.5 Protection

Geosynthetic materials protect the environmental soil from being erosion when used with the soil.

6.6 Containment

Geosynthetic materials help in isolating one material from another. This function is mainly used in landfill where geomembrane lining is placed to prevent the surrounding soil from being contaminated by inner waste.

6.7 Barrier

Geosynthetic materials act as a barrier between two kinds of materials as in GCLs when hydrated sodium bentonite swells 10 times its original weight and becomes effective barrier for liquid or gas.

6.8 Vibrational Energy Absorber

Geosynthetic materials placed as a lining under construction of roads, railways and building helps in absorbing energy caused during road traffic, running rails or during earthquake.

6.9 Thermal Insulation

Geosynthetic mainly as geoforms are used as a thermal insulation materials in building construction.

Different types of geosynthetic materials used in different applications are shown in Table 2.

Table 2 Types of geosynthetic and function

Type	Separation	Filtration	Drainage	Reinforcement	Protection	Containment	Barrier	Vibrational Energy Absorber	Thermal Insulation
Geotextile	√	√	√	√	√	√	√	√	
Geomembrane					√	√			
Geogrid				√					
Geocomposites	√	√	√	√	√	√	√	√	
Geonets			√	√					
GCLs							√		
PVD			√						
Geofoams								√	√
Geocuspates			√						

7.0 Application of Geosynthetics

Geosynthetic materials are used in various applications. Some of them are listed herewith

- Landfill Engineering
- Geotechnical Engineering
- Coastal Protection
- Rockfall Protection
- Canal Lining
- Flood Control
- Drainage system
- Infrastructure

8.0 Market Survey of Geosynthetics

In 2019, the global geosynthetics market size was valued at USD 13.96 billion and is expected to grow at a compound annual growth rate (CAGR) of 5.6% from 2020 to 2027. Lockdown measures imposed by the governing authorities to contain the spread of coronavirus is expected to create uncertainty regarding the growth of the market in the next couple of years.Strict government compliance such as mandate use of Geosynthetics by U.S. EPA in landfills under the Resource Conservation and Recovery Act (RCRA) and infrastructural development in India and Brazil is anticipated to contribute the market growth due to over the forecast period.

8.1 Productwise market share of geosynthetics

The geotextile product segment led the market and accounted for a 48.86% share of the global revenue in 2019. Geomembranes are estimated to expand at a CAGR of 4.4% in terms of revenue from 2020 to 2027 for application as floating covers for reservoirs to control evaporation, reduce the Volatile Organic Compounds (VOCs) emission, and minimize the demand for drainage and cleaning. Percentage wise distribution of geosynthetic product consumption is given in Fig 2.

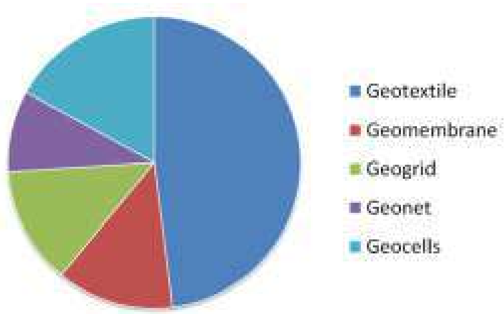


Figure 2 : Global geosynthetics market share by product 2019 (%)

8.2 Regionwise market share by geosynthetics

Asia Pacific led the market and accounted for over 41.0% share of the global revenue in 2019. Developing economies like China and India is expected to drive the regional market over the forecast period due to rising demand for oil reinforcement in the foundation work of residential buildings.

Europe accounted for over 20.0% share of the global revenue in 2019 due to various construction directives, such as 89/106/EEC and M/107 European Union, which has mandated the application of geosynthetics for infrastructure projects. Also, the German government imposed stringent regulations related to waste management practices in the municipal and industrial sectors.

Central and South America, including Brazil are likely to increase the use of geosynthetics due to increase in infrastructural activities in the coming years. Offshore oil and gas sector in Argentina, Venezuela, and Brazil is likely to drive the regional market. Increasing civil and commercial construction activities in the region of Middle East and Africa are likely to increase the demand of geosynthetics, over the forecast period.

9.0 Recent Developments in Geosynthetics

9.1 PLA based green geosynthetics

Green revolution is rapidly increasing in every construction sites in the world e.g., green such area structure, green installation, green industry and has led to development in green geosynthetics. PLA based geosynthetic materials is one such for researchers and to improve its biodegradability it is blended with PBAT (poly (butylene adipate-co- terephthalate) [13].

9.2 Smart Geosynthetics

Smart geogrids embedded with fiber Bragg grating (FBG) for reinforcement as well as the measurement of geotechnical structures have been developed. A paper studied the application of a distributed monitoring system to monitor a laboratory model slope reinforced with smart geogrids, in which the coherent optical frequency domain reflectometry technology (C-OFDR) was used to continuously monitor the geogrid deformations under different surcharge loadings [14].

9.3 Developments in Air Biaxial Tension Tests

Load-strain properties of geosynthetics determined from wide-width uniaxial tension tests are unable to account for stiffer load response due to biaxial loading. It is generally regarded as an index test. A paper presents the development of a biaxial testing procedure to provide load-strain response data necessary to determine in-plane linear elastic tensile properties of geosynthetics. In this, the load is applied in two principal directions and properties studied are two elastic moduli, two dependent in-plane Poisson's ratios and an in-plane shear modulus [15].

9.4 Electro kinetic geosynthetics

Geosynthetics have been identified to play an active role in initiating biological, chemical or physical change to the matrix in which it is installed. This can be done by combining the electro kinetic phenomena of electro osmosis, electrophoresis and associated electro kinetic functions such as electrolysis with the traditional functions of Geosynthetics. In a paper, a set of experimental and software analysis is done on expansive soils under various condition non saturated and fully saturated. Soil samples are tested by using prototype of cyclic loading disk (CLD). This copper is used as anode, aluminium as cathode and perforated PVC tube as drain system. Results show good improvements from lateral sliding and shear strength parameters [16].

9.5 Tri axial testing of multiple layer reinforced geogrids and geotextiles

In a research [17]shear properties and reinforced characteristics of multiple layer reinforced geosynthetic material were evaluated bytriaxial compression tests. Result shows that the geogrid stress–strain curves have hardening characteristics, while the geotextile stress–strain curves have strain-softening properties. With increase in reinforced layers, there is an increase in hardening or softening characteristics. However the reinforcement effect is more significant at a low confining pressure than at a high confining pressure.

9.6 Design of water retaining embankment using geosynthetics

In a study the author has proposed two alternative designs of water retaining embankment with internal drainage system with the objective of minimizing the use of sand by using geosynthetics.One is water retaining embankment with vertical drainage composite and other is water retaining embankment with horizontal drainage composite. Geosynthetics materials used are geotextile, drainage composite (geonet sandwiched by geotextile) and perforated pipe for filtration and drainage function [18] .

9.7 Improvement in shear strength of textured geomembrane (GMB) and nonwoven geotextile (GTX) in landfills

Textured geomembrane (GMB) and nonwoven geotextile (GTX) are usually used together in landfills, but during earthquake the stability of landfills are detrimental due to low shear strength of GMB/GTX interface. In a research[19], a series of displacement-controlled cyclic direct shear tests are conducted in dry and hydrated conditions with a large-scale direct shear machine to study the dynamic shear strength of the GMB/GTX interface. They showed that shear deformation develops along the GMB/GTX interface when specimens are fully hydrated, while the internal failure of GTX is induced in dry condition. A positive correlation is summarized between the shear strength and displacement rate of the interface.

9.8 Geosynthetic clay liners in the Antarctic environment

In a research [20], hydration/dehydration behaviour of geosynthetic clay liner (GCL) under polar conditions for four simulated conditions in Antarcticaviz; (a) hydration during summer, (b) dehydration during a winter-summer cycle, (c) hydration through a fine Antarctic soil, and (d) hydration through a coarse Antarctic soil were studied. Hydration in GCL during the summer is found to occur if there is direct contact with the water table. However dehydration occurs if there is low relative humidity of the environment. Hydration from either fine or coarse Antarctica soil depends on the original gravimetric water content of the subgrade soil, its grain size distribution, low relative humidity prevailing in Antarctica.

10.0 Conclusion

Geosynthetic materials are widely used in various applications and its global market demand is continuously growing. It provides cost-effective solutions for several engineering problems. This paper summarises different types of geosynthetic products, its manufacturing, functions, applications, its market survey and recent developments in geosynthetic products. Innovations in products, types and properties will continue to take place, adding to the already vast range of applications of these materials.

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Electrospinning Facility at BTRA

The nanofiber spinning machine at BTRA is a needle less solution spinning system from ELMARCO. The electrodes in the machine are wire type. Maximum width of the deposition is 50cm. Using this machine, we can spin continuously roll to roll. Paper, woven, nonwoven and knitted fabric can be used as substrate in the form of roll of 50cm wide. Maximum deposition time is 1min based on the minimum speed of the machine but we can increase the deposition thickness by passing the substrate multiple times. Variable spinning parameters are voltage 1-80kV, distance between the electrodes 80-180mm, relative humidity 45-80% and temperature 23-27°C. We have successfully spun PVA, PAN, Nylon 6, PLA. GSM of the deposited nanofiber can be adjusted by changing the substrate speed.

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