Geosynthetics — Its Functional Properties and Potential Applications

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Different polymeric materials along with natural fibres in the form of geosynthetics as woven, nonwoven, knitted or membranes have been used worldwide to improve the soil quality and performance in the different branches of geotechnical engineering. While there is a vital need for use of these functionally superior materials, their indigenous product is very essential from the application as well as from the end use point of view. This paper describes the essential and desirable raw material characteristics for the manufacturing of different types of Geosynthetics (including natural fibres like jute, coir etc), important physico-mechanical properties of such raw materials suitable for different end-uses of geosynthetics and their functional properties. An overview of different applications of geosynthetics suitable for various soil engineering related infrastructure development and their benefits in durability and in cost saving for road construction along with the control of soil erosion reinforcing of different civil engineering structures etc. have been discussed. Apart from this, this paper also deals with the different applications/uses of geotextiles from natural fibre (particularly, jute and coir) for different civil engineering applications. Simultaneously, this paper also brings out some basic elements of testing and standardisation of Geosynthetics.

Keywords: Geosynthetics; Geo-technical Engineering; Geotextiles; Jute Geotextiles (JGT); Polymeric materials

INTRODUCTION

Geosynthetics is the collective term applied to thin, flexible, sheets of material incorporated in or within soil to enhance its engineering performance[1]. However, fibrous materials have been used as reinforcing agents in buildings and civil engineering works since time immemorial. But the application of textile materials in civil engineering applications have matured as a well established material since 1960's[2].

Applications of geo-synthetics mainly fall within the domain of civil engineering applications. The specific design and specifications of such Geosynthetics materials for different civil engineering applications as related with the soils and can be considered as a part of geo-technical engineering. American Society for Testing and Material (ASTM) defines geosynthetics as a planner product manufactured from polymeric material used with soil, rock, earth or other geotechnical engineering related material as an integral part of a manmade project, structure or system[3]. However, there are some fabrics and waterproofing materials used in civil engineering which having similar appearances to geotextiles or geomembranes but these are not classified as geosynthetics. Consequently roofing felts and waterproofing materials would not be considered to be geosynthetics. The prefix 'geo' quite specifically implies an end use associated with improving the engineering performance of civil engineering works founded in, of or upon soil. In the vast majority of the cases the suffix 'synthetics' implies that geosynthetics are produced from manmade polymers though it may be designed from natural fibre materials as well. More precisely, the concept of making geotextile from manmade fibres originated from the use of natural ingredients in a variety of forms when textile technology and geo-technical engineering did not take full shape[4].

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Geosynthetics has a separate market segment have been developed and being used at an increasing pace for a greater number of geotechnical applications. No other materials known to the civil engineering community have experienced such a wide and rapid development and implementation as geosynthetics since their introduction. The Freedonia Group, a Cleveland, Ohio-based industrial markets research firm estimates the sales of geosynthetics are expected to increase 3.75% a year to \$1.3 billion in 2006[5].

CLASSIFICATION/FAMILIES OF GEOSYNTHETICS

The professional groups most strongly influenced are geotechnical engineering, transportation engineering, environmental engineering and hydraulic engineering, although all soil, rock and ground related activities fall within the general scope of various application. Ideally, a classification system for geosynthetic should include the constituent polymer or fibrous elements, the form/method of construction, weight/thickness, different functional properties, end use and engineering properties.

The specific families of geo-synthetics are focused on different categories[6], such as, geotextiles, geogrid, geonets, geomembranes, geosynthetic clay liners, geopipe, geo-composites and others.

Geotextiles

Geotextiles form one of the two largest groups of geosynthetics, which are textile fabrics (woven, nonwoven, knitted, braided, etc) specially designed to be used as constructional material in conjunction with other geotechnical materials such as soil and rock in applications of civil engineering nature. ASTM defines geotextiles as 'a permeable geosynthetic comprised solely of textiles'[3]. Geotextiles perform several functions in geotechnical engineering applications. The major point in favour of geotextiles is that they are porous to liquid flow across their manufactured planes and also within their thickness, but to widely varying degrees. There are at least hundred specific application areas for geotextiles; however, the fabric always performs at least one of five discrete functions[6], such as, separation, reinforcement, filtration, drainage and protection.

Separation

This function implies segregation of two or more layers of materials by preventing their intermixing either dissimilar materials or similar materials with different grading. The placements of a flexible porous textile between dissimilar materials so that the integrity and functioning of both materials can be remain intact or are improved.

Reinforcement

The synergistic improvement of a total system's strength created by the introduction of a geotextiles (that is good in tension) into a soil (that is good in compression but poor in tension) or into other disjointed and separated material.

Filtration

The equilibrium soil to geotextiles system that allows for adequate liquid flow with limited soil loss across the plane of the geotextiles over a service lifetime compatible with the application under consideration.

Drainage

The equilibrium soil to geotextiles system that allows for adequate liquid flow with limited soil loss within the plane of the geotextiles over a service lifetime compatible with the application under consideration.

Protection

The use of geotextiles in applications such as shoreline protection using rip rap, behind retaining walls or in channel lining systems has proven to be highly cost effective in reducing material loss and maintaining the integrity of the structure.

Advantages of Geotextiles

The principal advantages of geotextiles are described here.

Space Savings

Geotextiles occupy significantly less volume than comparable soil and aggregate layers.

Material Quality Control

Geotextiles are manufactured under controlled factory conditions, which minimize material variations, while soil and aggregate layer are proportional at batch plants.

Contraction Quality Control

Geotextiles require limited connections, while soil and aggregate layer are actually constructed in place and, therefore, are subjected to various caused by weather, handling and placement.

Cost Effectiveness

Geotextiles are less expensive to purchase, transport and install than soil and aggregate layer.

Technical Superiority

Geotextiles have been engineered for optimum performance, including greater strength, drainage efficiency and clogging resistance than soils and aggregates.

Broad Areas of Application of Geotextiles

The current major use of geotextiles is within the foundation components or load-supporting part of a civil engineering structure. In the main, any such structure (*eg,* building, embankment, dam, canal, road, railway[6,7] etc) transfers its load, *via,* its own foundation to the soil mass within and below it. The properties of soils under load are crucial to the stability of any civil engineering structure and it is to enhance soil stability that the use of geotextiles gained initial recognition as novel geotechnical materials. More recently geotextiles have been used to enhance tensile properties of civil engineering materials themselves, such as road surface and sub surfaces in both construction of new and renovation of old highways, mattresses for erosion control etc.

For the sake of easy understanding, different applications of geotextile have been classified into three groups, based on the influence they have made on the existing construction methods[8].

Group A

Geotextiles applications as the only feasible solution to overcome the shortcomings of the present construction practices, *eg*, rail bed stabilization; ground drainage; land stabilization; and new harbours and docks, etc.

Group B

Geotextiles application proving to be a better alternative to existing methods, *eg*, road construction and maintenance; canal lining; erosion control of seacoast and river embankment, etc.

Group C

Geotextiles application for novel construction techniques.

Classification of Geotextiles

Rankilor (1981) and Van Zanten (1986) have discussed in general, the fabric structures currently used for geotextiles and also seaming techniques, which enable their more effective use in the civil engineering environment.

Basically, all available geotextiles can be broadly classified into following categories on the basis of manufacturing techniques namely woven, nonwoven and knitting. The woven fabrics are made on conventional textile weaving machinery into with wide variety of fabric weaves. Woven geotextiles are preferred for applications where high strength and high modulus in the principal directions are more important considerations than similar properties in all other directions. Woven fabrics have an added advantage of engineered equivalent opening size because openings are regular and visible and can be correlated with soil particle size. Woven geotextiles are mainly used in coastal works, waterways, and embankment and in or near dams. Woven fabrics of special constructions are used in concrete forming.

Where as the initial demand of geotextiles were met by woven fabrics, the spurt in demand of geotextiles was observed only on introduction of nonwoven into geotextiles market. Nonwovens are made of individual fine fibres and hence they are comparatively more flexible and deformable and have lower modulus and higher elongation at breaks and shows favourable deformation under unrestrained conditions. This helps in spreading fabrics over uneven surface. But under restrained conditions, they resist deformation and help the fabric to keep position when geotextiles are positioned underground. Nonwoven fabrics as a group exhibit certain distinct properties[9] quite different from woven fabrics and these properties are shown in Table 1.

Table1 Comparison of properties of woven and nonwoven fabrics for use of geo-textiles

Properties	Woven	Nonwoven
Breaking Strength	Higher	Lower
Breaking Elongation	Lower	Higher
Initial Modulus	Higher	Lower
Absorption	Moderate	Very high
Bursting	High	Low
Thickness	Moderate	High
Opening	Can be regular	Irregular
Filtration	Moderate	Better
Porosity	Disadvantageous	Advantageous
Inplane Flow	Low	Can be high
Friction with Soil	Moderate	High

However, geotextile structures have involved combinations of the more conventional types, with knitted structures also being exploited on the basis of recent trends of geotextile features, a more classification of geosynthetic materials is shown in Figure 1.

RAW MATERIAL

The two most common manmade fibres used for the manufacture of geotextiles are polypropylene and polyethylene, but polyester is almost inevitably used when high strengths are required. Considering the balance of cost against performance in geotextile applications, polyester is the suitable one. Polyamide is rarely used in geotextiles. For some woven geotextile materials polyamide have been used in the weft direction, more as a filler yarn. In Japan, polyvinylidene chloride is also used as geotextiles for different geotechnical solutions.

Apart from synthetic fibres, the natural fibres are also playing very important role as a raw material in the field of different geotextile applications. It is evident that the concept of geotextile as an agent to improve engineering properties of soil originated from the age-old use of natural fibres10 and produces in making of pathways and in controlling erosion in coastal and riverbank along with the construction of rural road.

Selection of natural fibre for geotextiles are influenced by their mechanical and general properties of available natural fibres in terms of strength, elongation, flexibility, durability, availability, variability and their textile forms controlling/influencing porosity, air and water permeability, filtration property etc. from the civil engineering and textile aspects. Considering those property

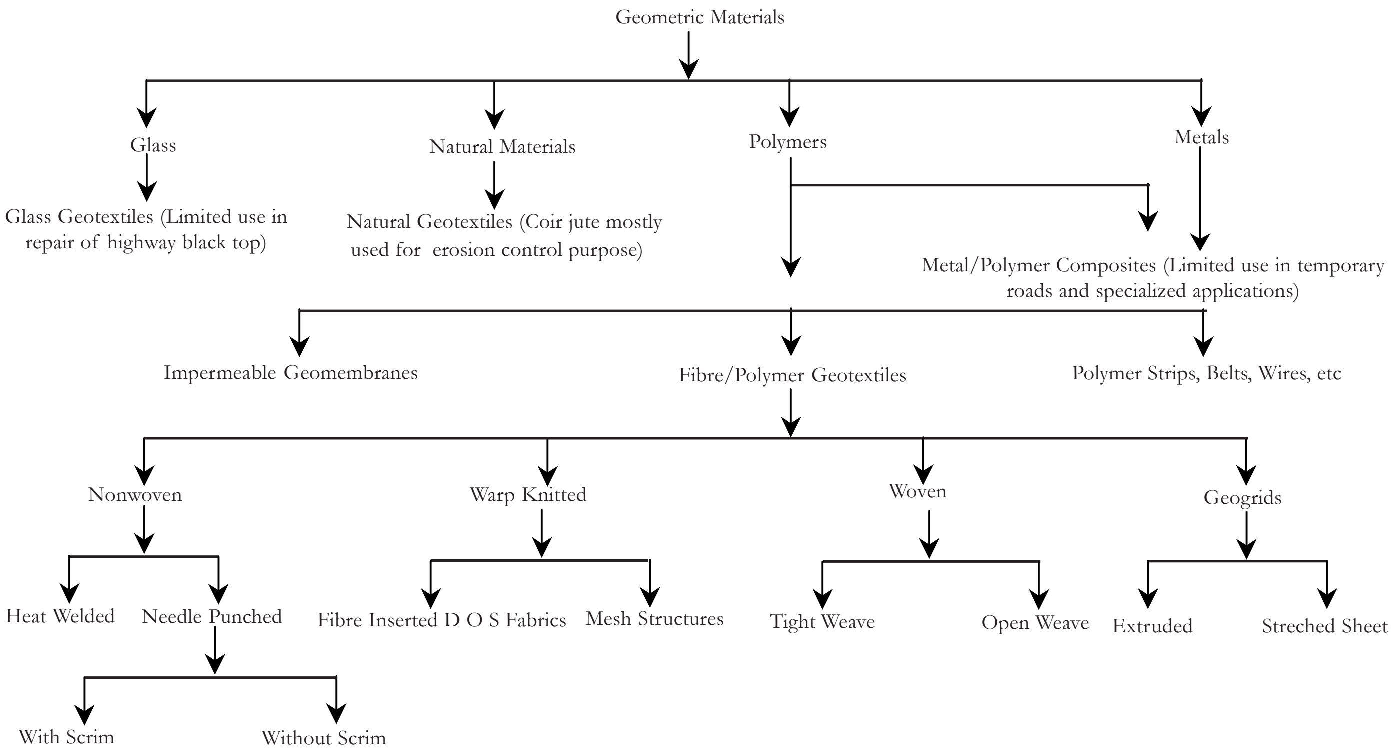

Figure 1 Classification of geopolymeric materials in terms of geotextiles, geogrids, geomembranes, related products and subgroups thereof [Rankilor and Raz, 1989]

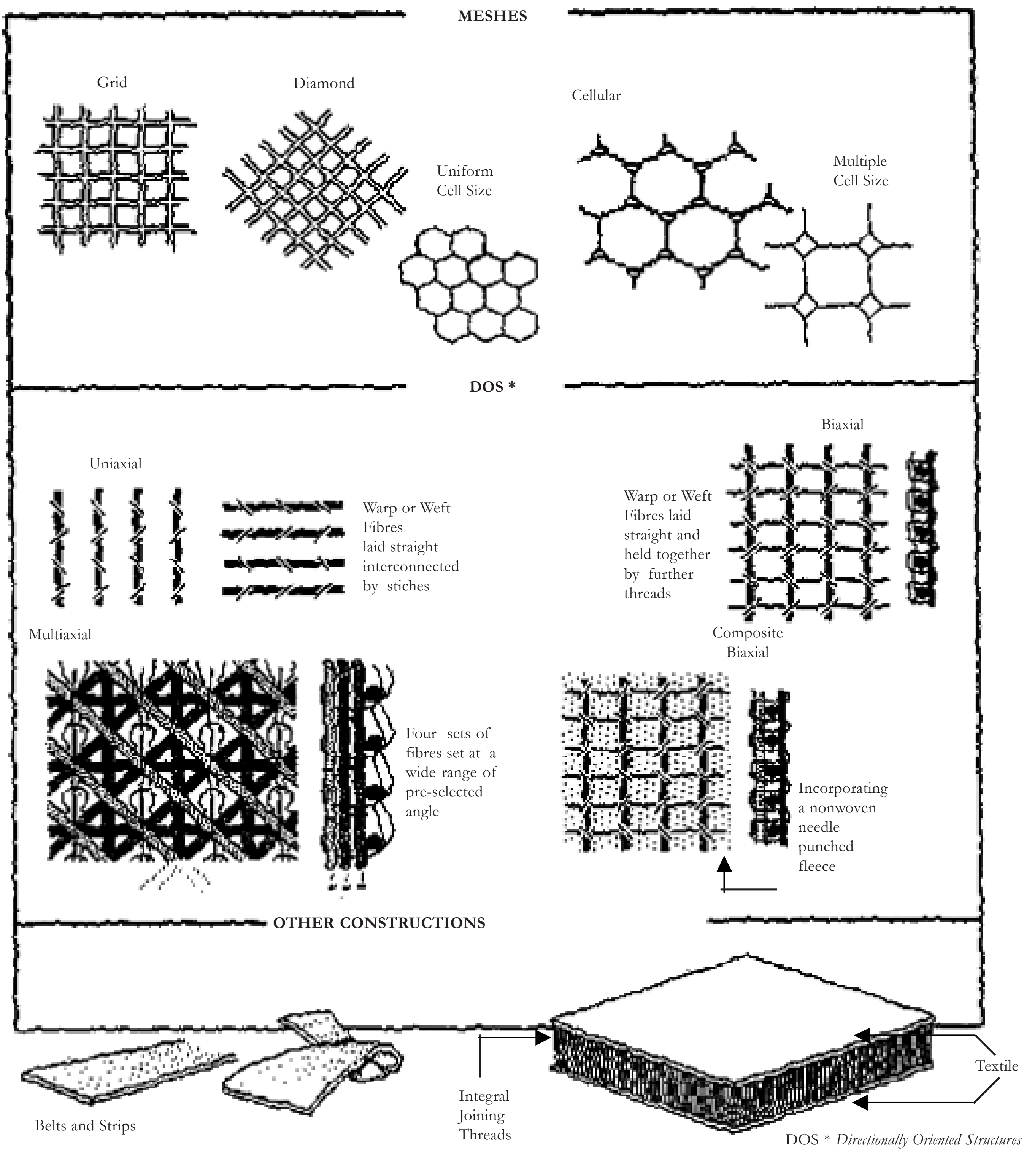

Figure 2 Directionally structured fibres (DSF) geotextiles (Rankilor, 1988)

parameters, six vegetable fibres have been selected as the most promising to form geotextiles are flax, jute hemp, abaca, sisal and coir for different geo-textile application. Table 2 shows the different property parameters of some synthetic (man-made) fibres in comparison to those properties of jute, to understand the suitability of those as geotextile materials with respect to different end use.

JUTE GEOTEXTILES

Jute geotextiles (JGT) can be described as natural fibre materials used for civil engineering purpose to meet technical as well as functional requirements for soil related problems. It is the agro-renewable natural fibre material as well as economical and eco-friendly (bio-degradable)

Table 2 Comparison of some basic properties of different synthetic fibres and jute fibre, for understanding the suitability of their use in geotextiles[2,11,12]

Property Parameters	PET	PP	LDPE	HDPE	PA	Jute
Density, kg m^{-3}	1380	900-910	920-930	940-960	1450	1450
Crystallinity, %	30-40	60-70	40-55	60-80	90	50-55
T_g, ^{0}C	75	-15 to 10	-100	-100	340	--
T_m, ^{0}C	250-260	160-167	110-120	125-135	550	--
Tensile strength, GNm^{-2}	0.8-1.2	0.6-0.8	0.08-0.25	0.35-0.60	2-2.8	0.43-0.71
Breaking strain, %	8-15	10-40	20-80	10-45	2.6	1-2
Initial modulus, GNm^{-2}	8-11	5-8	2-4	3-6	50-100	17-28
Moisture regain, % at 20^{0}C, Rh, 65%	0.4	0	0	0	3	12

PET:Polyethylene Terepthelate; PP:Polypropylene; LDPE:Low Density Polyethylene; HDPE:High Density Polyethylene; PA:Polyaramid

answer to geo-technical problems. There are several advantages of jute geotextiles arising out of its inherent distinguishing characteristics, which make them eco compatible and soil friendly for the purpose of soft soil consolidation, village road construction, erosion control and protection of canal slopes, river bank and coastal areas, stabilisation of earthen embankments in sides of the ponds, slope management and surface soil erosion control etc and also as agricultural net (geo-net), mulching fabric for vegetation and bio-technical support, etc.

JGT finds its application in the following areas of civil engineering applications.

- Surface soil erosion control in slopes and plains
- Stability of embankments (roads/railways/flood)
- Strengthening of sub-grade in roads
- Protection of banks of rivers and waterways
- Sub-surface drainage
- Soft soil consolidation

And other sectors where JGT can successfully be used are agriculture, horticulture and forestry.

Jute and Its Different Properties

Jute is renewable and eco friendly natural bast fibre and has properties very suitable for many technical applications in the area of geotextiles. Major draw backs of jute for use as geo-textiles are its low strength and poor durability; however its biodegradability and soil friendly nature has proved its natural preference over the synthetic geotextiles, which is found as advantageous also on indicative cost comparison between the two. Even in comparison to other natural fibres, jute geo-textiles have certain advantages. Followings are the advantages offered by jute fibre as JGT in comparison to other available natural fibres.

- High moisture absorbing capacity;
- Required drapability of jute fabric;
- High initial tensile strength;
- Can be tailor-made in designing JGT for different purpose;
- Biodegrability and soil friendliness;

Table 3 Product range available for jute geotextiles[13]

Properties	Type			ASTM Test Method
	Open Mesh Woven Geotextiles for Control of Surface and Erosion	Typical WovenGeotextiles for Separation and Filtration	Nonwoven Geotextiles for Filtration and Drainage	
Weight, g/m^2	292-730	760-1200	500-1000	D-5261-92
Threads, dm (MD x CD)	12-7x12-7	102x 39	--	--
Thickness, mm	3-7	2-3	4-8	D-5199-01
Open area, %	80	--	--	--
Width, cm	122	76	150	--
Strength, kN/m (MDxCD)	10-12 x10-12	20-21x 20	4-6x 5-7	D-4595-86
Elongation at break, % (MDxCD)	--	10x10	20x25	D-4595-86
Pore size, (O_{90}), μ	--	300-150	500-300	D-4751-99a
Coefficient of water permittivity, 10^{-3}m/s	--	--	3.4- 0.34	D-4716-01
Water permeability at 10cm water head, l/m^2/s)	--	50-20	--	D-4491
Puncture resistance, N/cm^2	--	380-400	--	D-4833
Water holding capacity, % on dry weight basis	400-500	--	--	--
Maximum durability, yr	2	1-4	1	D-4355 and 4594

- Agro-renewable resource and easily available; and
- Economical.

JGT withstands stresses in the constructional phases, prevents intermixing of different soil layers, acting as separator, performs filtration function and also controls lateral dispersion, subsidence and slides.

As a totality, JGT performs five basic functions such as separation, filtration and drainage, initial reinforcement, control of surface soil detachment and vegetation or biotechnical support, which have been discussed earlier.

Specifications of Standard JGT

Apart from jute and coir, no serious attempt has so far been made to manufacture of geotextiles from the other natural fibres. Jute and coir have lately made ingress in the field with prospects of clinching apart of the market as the selection of the right type and quality of JGT for a specific application is of vital importance. Table 3 shows the product range available for jute geotextiles for different geotechnical applications.

GEOTEXTILE PROPERTIES AND TEST METHODS

Testing of Geotextiles

In a growing area of specific use, such as geotextile, unified set of worldwide standards and test methods are currently not available, yet the activity towards such ultimate goal is very intense. In any review of available geotextile testing methods to follow, it should be recognised that many of the testing instruments and test methods are not fully standardised. The tests that differ for general textiles and geotextiles materials are those involve hydraulic, airo-dynamic, soil compatibility, endurance and environmental properties; which are generally newer tests oriented/designed separately considering geotextile applications. However, for testing of geotextiles, some standards have been emerged even though these are not a complete full standards required. Such available standards are ISO, PIARC, EDANA, NRRL, CRIS, and CEN etc but in the U S the ASTM has a standard committee specially organised for geosynthetics (D-35) testing methodology, which is very much useful and convenient for different geo-textile applications in the field of civil engineering discipline. Therefore, it is evident from the above discussion that the respective standards for testing of geo-textile materials should be chosen with respect to different application from the perspective of product design and engineering concepts. However, Geotextile testings[14] are required for the following purposes.

Control of Product Specifications

For maintaining quality and standard of the product for specific end-use.

Comparison of Product

Index testing for comparison with standard specification or with other products.

To fulfil above requirements, following tests along with different available standard test method of ASTM for carried out of assessing geotextile materials with respect to different end uses is given here.

Properties	ASTM Test Method
Weight/Unit area	D-5261-92 (1966)
Thickness	D-5199-01
Tensile strength and elongation test - Strip tensile test method	D-4595-86
Tensile strength and elongation test - Grab tensile test method	D-4632
Plane tensile test	D-4885
Wide width tensile strength test, Creep test	D-5262-02a
Bursting strength test and impact tear strength test etc.	D-3786 and 5884
CBR (California bearing ratio) plunger test	D-6364-99
Cone plunger test	D-5617-99
Trapezoidal tear test	D-1117
Pore size determination - dry	D-4751-99a
Water flow test, normal	D-5493-93 (1998)
Water permeability test	D-4491
P1anar water flow test	D-4716-01
Soi1against fabric friction test and soil retentivity test	D-5321
Abrasion resistance test and fatigue resistance test	D-4886 and 6243
Ultra violet light degradation test	D-4355
Test for resistance to weather, temperature and chemicals, etc	D-4594 and 5747
Rot resistance or soil-burial determination test, etc	D-5819

Relevant Fabric Properties for Geotechnical Applications

The selection of a fabric for a particular application in Geotextile Engineering must necessarily depend upon adequate and suitable fabric properties and characteristics. If these properties are inadequate, a failure will result. On the other hand, if these properties are excessive the selection of fabric may be uneconomical. The safest and ideal way of selecting the fabric is through case study/test-use of the products and comparison of performances in the field projects by observations and necessary testing. But incidentally, very few historical case studies are available for jute geotextiles for comparison. As a result, an evaluation of the fabric for a particular geotextile application is made on the basis of simulated or standard laboratory tests[15]. On basis of knowledge gained through experience, fabric properties relevant for geotextile applications are broadly divided into three groups namely, a) Mechanical properties (b) Hydraulic properties and (c) Endurance and miscellaneous properties.

Important Mechanical Properties of Geotextiles

For geotextiles, important mechanical properties those are to be considered for understading its common performance and serviceability are Weight (mass), Thickness, Compressibility, Tensile Strength, Elongation, Tear Strength, Abrasion Resistance and Fatigue, etc. which are commonly known to all technical personnel and need no further discussion. However, more important are some of the hydraulic properties of geotextiles for understanding its application wise functional performance, which therefore are discussed in this paper.

Important Hydraulic Properties of Geotextiles

Porosity or Opening Pore Size of Fabric

This is the most important property of fabric as far as drainage is concerned. Most accurate method of deciding porosity is by using Image Analyzers', which adopts scanning technique. The method is most accurate but high initial equipment cost is the limitation of the method. Equivalent Opening Size (EOS) test is another method commonly used to find out opening size of fabric. The test uses known sized glass beads of designated EOS numbers and determines by sieving that size of beads for which five percent (5%) or less pass through the fabric. This is also called retained on EOS number of the fabric.

Air Permeability

It is defined as the rate of airflow through a fabric under a differential pressure between the two fabric surfaces. It is usually expressed in $ft^2/m/ft^2$.of fabric between the stated differential pressures.

Water Permeability

This test is aimed at judging the Water Permeability of fabric in relation to water permeability in soil. The method mainly applies water pressures of different heads on fabric and measuring flow rate of water. It is expressed either as cm/s as the water-head pressures ranges from 31" to 36" or is expressed as gallons/min/ft^2 at a constant water-head pressure.

Planar Water Flow

The ability of fabric to carry water horizontally in its manufactured plane at different positive and sometimes even at negative water-head pressures is a very important property as far as drainage application is concerned. This involves syphonage ability of the fabric. Attempts have been made to develop standard test methods for the same.

Gradient Ratio Test

The gradient ratio is defined as the ratio of seepage gradient through the fabric and 1" of soil to gradient through an adjacent 2" of soil. This ratio helps as an indicator of binding or clogging of the fabric. By reversing the direction of flow, one can arrive at upward gradient test which helps in deciding cake forming capacity of the fabric.

Soil Retentively

Soil water suspension when allowed to pass through fabric at differential known pressures can be used to determine soil passing through a given fabric at different velocities and in turn may help in deciding soil retentively of the fabric

Fabric Piping Performance

If the flow gradients from soil become too large for the fabric to retain them, failure of the fabric will result. When the soil water suspension is flowing upwards the flow at which soil column beneath the fabric and on both sides of the fabric causes blow out is termed as the measure of piping performance.

Fabric Endurance and Other Miscellaneous Properties of Geotextiles

Resistance to Chemicals

Resistance of geotextiles to various chemicals has been studied and various methods have been reported to study the same in terms of changes in weight, dimensions, appearance and strength and elongation properties etc. These observations are also extended for various time exposures and for different temperatures.

Resistance to Light and Weather

This property of geotextiles is tested to study long term behaviour of fabric in operation and includes factors such as climatic conditions, time of year, atmospheric conditions and so on. In effect, exposure test samples should simulate service conditions of the end use conditions as far as practical. It is important to note that exposure of textiles to ultraviolet light cause and rapid degradation of strength. Therefore, geotextiles should not be exposed to such conditions or should be so treated to eliminate such accelerated degradation. Polypropylene a widely used geotextile material is highly susceptible to degradation on exposure to ultraviolet exposure.

Resistance to Temperature

Resistance to Temperature of geotextiles is studied mainly in two ways namely, continuous heating and cyclic heating. In first case, the heat is gradually increased, till the failure occurs. Failure is decided by change in appearance, weight, and dimension or by any other relevant property, which renders the product unserviceable for the specific end application. In the second case, heat of constant value is repeatedly applied until failure. These observations apart from other things indicate the method of measures, to be adopted while placing hot materials such as asphalt or sealers on geotextiles. The effect of 'high and low' temperatures on geotextiles with particular reference to brittleness and impact strength are also considered important. However, such studies demand larger sample population and observations should be arrived at on the basis of statistical value only.

Burial Deterioration of Fabric

It has been recognized that the soil is a variable factor. Soil may be 99% organic to 100% inorganic. It can have pH value of great range varying from highly acidic to highly alkaline. Its elemental and microorganism contents can vary drastically. Burial Deterioration test, therefore, involves burial of geotextile samples in different soils under natural conditions. Samples are removed at intervals of three months and tested for tensile strength and bursting strength, etc.

CONCLUSION

With the recent emphasis on worldwide infrastructure development, geosynthetics have received tremendous boost. From ocean bed to road construction, from foundation on soft soil to landslide control, from waste disposal site to water reservoir, geosynthetics have found an important place for themselves in engineering and construction project world over. Apart from conventional civil engineering application, it is being established that even in environmental engineering application including pollution control, landfill, erosion control and geosynthetics are beginning to play a major role. When geosynthetics are used in a specific application or in the solution of a particular engineering problem, it is for the designer to determine what properties are required. Provided that the properties specified by the designer are teneable then the selection of geosynthetics, which complies with the specification, is the first step in the design being realized as the constructed works. This process may be regarded as a statement of the obvious, but it is surprising how frequently products with predetermined properties are marketed as being the solution to the given engineering problem on application. In short role of the designer is to specify the properties required of a geosynthetics to solve a specific problem rather than starting with geosynthetics of predetermined properties and defining the problem, which this geosynthetics might solve. Thus for Jute Geotextiles, number of different type of fabric specifications are to be tried for specific end uses as a case study to get or to standardized a particular type of JGT for that particular purpose. Some case studies are already available (though not complete in many direction) which may be used as a guideline. However to popularized and established jute geotextiles in the civil engineering applications, a constant effort and interaction is necessary.

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