Geosynthetics Asia'97, 26–29 November, Bangalore, India

GEOSYNTHETIC TESTING—RECENT DEVELOPMENTS

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ABSTRACT

Testing and evaluation of Geosynthetics is a key issue which can ensure successful performance. While majority of the physical and mechanical properties can be obtained through current test standards, further research provides a tool for imrovement over existing practices and also devise new methods where none exist. In this context, information is included in this paper on valuable information one can obtain by pore size distribution determination. The general and tensile behaviour of natural fibre geotextiles is also delineated, that should pave the way for their standardization.

INTRODUCTION

With the wide variety of geosynthetic products currently available to serve the variety of applications that are called upon in civil engineering, their selection is not very easy. Only the right kind of product will be able to serve the specific need. The performance can only be ensured by a particular set of properties. In other words, property characterization is the key issue. Holtz, Christopher and Berg (1995) and Christopher (1996) have brought out an excellent state-of-the-art on the subject. Hence only a few issues that attracted attention will be touched upon.

Christopher (1996) presented the important criteria and principal properties required for geosynthetic evaluation (Table-1). He also summarised the various standard test procedures that are currently available. While specific test procedures are already identified the world over, by ASTM, BS, DIN, EC, ISO, GRI and other organisations, research is on to prove the validity of some of the techniques and identify newer techniques. Also notice some ? in Table-1 marked by Christopher. Even these need to be addressed to. Keeping this in view, this Keynote Lecture will focus attention on some recent research findings at IIT Delhi on polymeric geotextile testing and the hitherto neglected area of natural geotextile testing. More specifically some of the work carried out on index testing and performance/durability testing of natural geotextiles will be addressed.

BACKGROUND

Since 1986, at IIT Delhi - both at the Civil Engineering Department and Textile Technology Department - attempts have been made to understand the behaviour of

TABLE 1
IMPORTANT CRITERIA AND PRINCIPAL PROPERTIES REQUIRED FOR GEOSYNTHETIC EVALUATION

(After Christopher, 1996)

CRITERIA AND PARAMETER	PROPERTY	FUNCTION					
		Filtration	Drainage	Separation	Reinforcement	Barrier	Protection
<u>Design Requirements:</u>							
Mechanical Strength							
Tensile Strength	Wide Width Strength	–	–	–	✓	✓	–
Tensile Modulus	Wide Width Modulus	–	–	–	✓	✓	–
Seam Strength	Wide Width Strength	–	–	–	✓	✓	–
Tension Creep	Creep Resistance	–	–	–	✓	✓	–
Compression Creep	Creep Resistance	–	✓	–	–	–	–
Soil-Geosynthetic Friction	Shear Strength	–	–	–	✓	✓	✓
Hydraulic							
Flow Capacity	Permeability/ Permittivity	✓	✓	✓	✓	✓	–
	Transmissivity	–	✓	–	–	–	✓
Piping Resistance	Effective Opening	✓	–	✓	✓	–	✓
Clogging Resistance	Porimetry	✓	–	–	–	–	✓
	Gradient Ratio or Long-Term Flow	✓	–	–	–	–	✓
<u>Constructability Requirements:</u>							
Tensile Strength	Strip/Grab Strength	✓	✓	✓	✓	✓	✓
Seam Strength	Strip/Grab Strength	✓	✓	✓	–	✓	–
Bursting Resistance	Burst Strength	✓	✓	✓	✓	✓	✓
Puncture Resistance	Rod or Pyramid Puncture	✓	✓	✓	✓	✓	✓
<u>Longevity (Durability):</u>							
Abrasion Resistance	Reciprocating Block Abrasion	✓	–	–	–	–	–
UV Stability	UV Resistance	✓	–	–	✓	✓	✓
Soil Environment	Chemical	✓	✓	?	✓	✓	?
	Biological	✓	✓	?	✓	✓	?
	Wet-Dry	✓	✓	–	–	–	✓
	Freeze-Thaw	✓	✓	–	–	✓	–

geosynthetic materials - be it general properties, index testing or performance testing. Apparatus have been fabricated/developed to delineate their characteristics in terms of

- Physical properties
- Mechanical Properties (Tension, Interface Friction, Hydraulic)
- Construction survivability properties
- Durability characteristics.

The results have been presented in various fora beginning with Venkatappa Rao and Raju (1990) and more recently in Venkatappa Rao (1996) and the Proceedings of the International Seminar and Technomeet on Environmental Geotechnology with Geosynthetics (Venkatappa Rao and Banerjee, 1996) held in New Delhi during July-August, 1996. Only some specific issues on polymeric geotextiles are taken up here.

It is well known that India produces vast quantities of Jute fibre and Coir fibre and has a major share in the world market. While geotextiles with natural fibres are being manufactured in India, neighbouring countries and elsewhere in the world, their use is limited, despite their being environment friendly. While the issues relating to this will be discussed separately by Prof. Banerjee, some reasons are not difficult to guess. There is hardly any literature on their testing and evaluation. More particularly, their biodegradability - which always appeared to be a matter of conjecture, but could be used to advantage. The results of a systematic effort towards characterizing natural geotextiles are also highlighted in this paper.

POROMETRY OF GEOTEXTILES

The hydraulic characteristics of geotextiles are closely related to the porometry i.e. the properties related to the pores of the geotextiles. The apparent opening size (O_{95}) is one of the most commonly used parameters of porometry. It is equal to the size of the largest particle that can effectively pass through the geotextile in a sieve test.

Hydrodynamic Sieving Test

In the hydrodynamic sieving test apparatus developed at IIT Delhi the geotextile specimen, loaded with a certain quantity of glass bead fraction, is continuously rotated in a water trough forcing the glass beads to pass through the geotextile openings. After a test period, long enough to ensure that all fine particles had passed, the percentage of passing of different fractions determines the porometry of the geotextile investigated. The apparatus shown in Fig. 1 essentially consists of the following:

i) A test drum of 140 mm diameter and 70 mm unobstructed length provided circumferentially with equally spaced 16 numbers of 4 mm diameter rods to hold the geotextile in position.

ii) A trough, to contain the test drum supported on a horizontal axis facilitating free rotation and capable of being filled with distilled water to a level 20 mm below the drum axis. The drum is mounted so as to allow an unobstructed clearance of 40 mm between the trough and the geotextile.

iii) A motor drive capable of rotating the drum at a speed of 5 rpm to 30 rpm.

By conducting a preliminary investigation, the optimal working conditions of the apparatus for a fractioned spherical glass beads of 50 g that were selected are: i) A cycle speed of 20 rpm, and ii) A test duration of 1500 cycles.

Table 2 presents the O_{95} values with dry sieve test as compared to hydrodynamic sieve test which is attributed to the non-renewal of the geotextile specimens for different glass beads. In case of dry sieving method, the glass beads entrapped in the geotextile fabric structure are possibly released when the consecutive larger fractions were sieved in the same geotextile specimen. On the other hand, a new geotextile specimen used for each glass bead fraction in the hydrodynamic sieve test provides more representative O_{95} value because of the larger surface tested.

The investigations on the dry sieving and rotating type hydrodynamic sieving test methods did not yield significant difference in O_{95} values. The latter test is preferable for the following reasons:

i) In the dry sieve test method, the vibratory movement is not well defined and gives divergent results.

ii) The simulation in Hydrodynamic methods is more closer to the field condition.

iii) The presence of water eliminates the influence of electrostatic charges.

iv) The coefficient of variance of O_{95} value is less than the dry sieve test method indicating good reproducibility of the test method.

Variety of geotextiles prepared

With a view to develop a mathematical model for designing needle punched geotextiles in hydraulic applications, an extensive work was undertaken at the Textile Technology Department of Indian Institute of Technology, Delhi (Dey, 1995; Banerjee et al., 1996).

After an extensive review of literature, five material/ process variables, viz.,

- fibre fineness (FD)
- fibre length (FL)
- batt areal density (BAD)
- depth of penetration of needle (DOP), and
- punching density (PD)

have been identified as the most important factors. By the prevailing commercial range, five levels of each factors were chosen for polyester and polypropylene fibres respectively (the most commonly used fibres) as indicated in Tables 3 and 4 respectively. An orthogonal, rotatable, central composite experimental design (CCD) of second order was used for sampling plan. Employing a full factorial design, (Table 5) 59 fabric samples from polyester fibres and 36 fabric samples from polypropylene fibres were developed on a needle punching machine (manufactured by 'Asselin' of France) employing transverse laying principle.

Each of the fabric samples so generated was subjected to tests for 28 different fabric properties, yielding thus in all about 40,000 data. Table 6 lists the different fabric properties investigated. Some of the tests had to be carried out separately for two principal fabric directions whereas some of the tests such as the thickness and flow properties had to be carried out under different hydraulic head and/or normal pressure. A general range of values of typical properties is given in Table 7, from which it is evident that the properties of the fabrics fall in the normal range of presently available geotextiles. In an effort to provide a compact shape as well as a mathematical form to this large volume of test data various statistical techniques were employed with different data sets. Test results obtained, after

Table 2 **Summary of the O_{95} values of geotextiles obtained from dry sieving and hydrodynamic sieving test methods**

Geotextiles	Thickness (mm)	Mass/area (g/m^2)	O_{95} dry sieving test (ASTM) (μm)	O_{95} hydrodynamic sieving test (μm)
NW_1	2.13	290	84	80
NW_2	4.15	470	97	87
NW_3	2.07	195	147	140
NW_4	2.02	240	117	103
NW_5	2.06	205	147	135
W_1	0.58	206	102	106

Table 3 Different Input Variables and Their Levels for Polyester Fabrics (After Banerjee et al. 1996)

Level Nature	Variables	Level of Variables				
		Axial point (-α)	Factorial Point (-β)	Center Point (O)	Factorial Point (+β)	Axial Point (+α)
Coded	All	-2.378	-1	0	+1	+2.378
Actual	Fibre Fineness (denier) (X_1)	2.12	3.5	4.5	5.5	6.88
	Fibre Length (mm) (X_2)	39.33	60.00	75.00	90.00	110.67
	Web weight (g/m^2) (X_3)	102.2	240.0	340.0	440.0	577.8
	Depth of penetration (mm) (X_4)	8.05	11.5	14.0	16.5	19.95
	Punch density (Punch/cm^2) (X_5)	50.00	160.0	240.0	320.0	430.0

Table 4 Different Design Input Variables and Their Levels for Propylene Fabrics (After Banerjee et al. 1996)

Nature of Value	Variables	Level of Variables				
		Axial point (-α)	Factorial Point (-β)	Center Point (o)	Factorial Point (+β)	Axial Point (+α)
Coded	All	-2	-1	0	+1	+2
Actual	Fibre fineness (denier) (FD)	3.0	6.0	9.0	12.0	15.0
	Fibre length (mm) (FL)	45.0	60.0	75.00	90.0	105.0
	Batt Areal Desntiy (g/m^2) (BAD)	140.0	240.0	340.0	440.0	540.0
	Depth of Penetration (mm) (DoP)	9.00	11.5	14.0	16.5	19.0
	Punch desntiy (Punch/cm^2) (PD)	80.0	160.0	240.0	320.0	400.0

Table 5 Breakup of Treatment Combinations (After Banerjee et al. 1996)

Fibre	No. of Variables	Nature of design	No. of Treatments/Trials			
			Factorial	Axial part	Centre Part	Total
Polyester	5	Full factorial	$2^5 = 32$	2x5 = 10	17	59
Poly-propylene	5	Half factorial	$2^{5-1} = 16$	2x5 = 10	10	36

Table 6 List of the fabric properties investigated

Criteria	Properties
Dimensional properties	Width, Weight, Areal density, Thickness, Compressibility, Recovery constant and Bulk density of the fabric
Survivability properties	Strength, Elongation, Tenacity, Tear Strength, Ball bursting strength, Puncture resistance and Cone drop
Hydraulic properties	Porosity, AOS, Mean distribution radius, Pore size distribution parameter, Mean pore radius 25, permittivity and Permeability, Transmissivity, Cross Plane flow and In-plane flow

Table 7 Range of values of typical dimensional, survivability and hydraulic properties of Polyester and Polypropylene needle punched fabric samples (After Banerjee et al. 1996)

Properties	Material			
	Polyester		Polypropylene	
	Max.	Min.	Max.	Min.
Areal density (g/m^2)	440	100	512	107
Thickness (mm)	3.5	1.7	4.0	1.8
Strength (MD) (kN/m)	12.1	2.6	15.3	2.8
Strength (CMD) (kN/m)	24.1	5.6	43.6	5.0
Elongation (MD) (%)	158	77	167	105
Elongation (CMD) (%)	139	68	149	70
O_{95} (μm)	175	46	263	87
Permittivity (sec^{-1}) (2 kPa & 5 cm)	0.136	0.039	0.150	0.056
Transmittivity (cm^3/s/cm) (2 kPa & 5 cm)	0.233	0.044	0.619	0.109

MD - Machine direction, CMD - Cross machine direction

Table 8 **Estimated co-efficient of correlation values (pearson) of the hydraulic properties of polyester fabrics.**

	AOS	CRFLOW	INPLFLOW	MDR	MR25	MR50	MR75	MR95	PPC2	PSDP	PTC2
AOS	1.000	--	--	--	--	--	--	--	--	--	--
CRFLOW	0.375	1.000	--	--	--	--	--	--	--	--	--
INPLAFLOW	0.420	0.716	1.000	--	--	--	--	--	--	--	--
MDR	0.660	0.608	0.717	1.000	--	--	--	--	--	--	--
MR25	0.673	0.638	0.808	0.932	1.000	--	--	--	--	--	--
MR50	0.610	0.283	0.499	0.620	0.728	1.000	--	--	--	--	--
MR75	0.232	-0.049	0.161	0.219	0.338	0.624	1.000	--	--	--	--
MR95	-0.056	-0.076	0.127	0.086	0.084	0.293	0.626	1.000	--	--	--
PPC2	-0.483	-0.720	-0.755	-0.819	-0.828	-0.471	-0.084	-0.012	1.000	--	--
PSDP	0.691	0.629	0.847	0.885	0.911	0.629	0.220	0.104	-0.834	1.000	--
PTC2	-0.491	-0.597	-0.859	-0.741	-0.809	-0.459	-0.151	-0.044	0.826	-0.806	1.000

being subjected to relevant statistical treatments, were used for developing statistical models. The Stepwise regression method, a multiple regression technique, was employed for developing the models of geotextile responses under change in any input variables. Thus for each geotextile property evaluated, one second order regression model was worked out.

Pore Size Distribution through Mercury Porosimetry

Special attention was paid to the study of porometry employing mercury intrusion method. To this end a Quanta Chrome Auto scan 33 porosimeter with sub ambient scanning facility was employed. Following the standard experimental procedure it was observed that pores larger than 200 μm could not be reduced owing to the minimum mercury pressure corresponding to a height that the mercury had to climb before the size measurement could start. To obviate the problem a suitable modification was carried out on the bell jar. The specimen holder was also suitably modified.

The output of an experiment with the mercury porosimter is a plot of cumulative volume of mercury intruding in the pores of a fabric sample as a function of mercury pressure. A typical plot is shown in Fig. 2 (after Dey 1995). Depending on the nature of the intrusion curve about 50-100 data points were retrieved from each plot for detailed analysis of pore characteristics of geotextile. From this data, volume pore size distribution function $D_v(r)$ was calculated and plotted as a function of pore radii of the fabric as shown in Fig. 3 (after Dey 1995).. A computation of the coordinates of this plot leads to Mean Distribution Radius (MDR) which contains the weighted contribution of each class of pore. This volumetric pore size distribution plot can also be fitted to a Rayleigh distribution with single parameter as shown in Fig. 4 (after Dey 1995). This pore size distribution parameter forms an additional representation of the nature of pore channels. In order to work out distribution of number of pores as a function of pore radius, the model proposed by Tang Luping (1986) was employed. This model is applicable for bodies with porosity less than 0.8478 and having cylindrical pores crossing perpendicularly in three-dimensional space - condition which the needle punched fabric samples come close to satisfying. A typical distribution is shown in Fig. 5 (after Dey, 1995). This distribution was also fitted to a Rayleigh function (PSDP). Such a plot can be effectively used to read out values of mean pore radius (MR) greater than 95% (MR 75) or 25% (MR 25) of the total number of pores in the fabric - along lines similar to the concept of AOS.

Relationship among Different Hydraulic Properties

Flow properties and porometry i.e. properties related to the pores of the geotextiles were estimated independently by using their respective standard test methods by using apparatus described in Venkatappa Rao (1996). Depending on the application, these properties have their own relevance. Since all these techniques are based on some simplified assumptions and provide only a relative estimate of the respective properties, their degree of association may not always be identical. In order to estimate the strength of association, co-efficient of correlation among various hydraulic proerties, estimated in the present study, were computed. The estimated co-efficient of correlation values (Pearson) for both polyester and polypropylene geotextiles are listed in Table 8 and Table 9 respectively. A systematic analysis of the data revealed the following:

1. For both polyester and polypropylene geotextiles all the porometry related data have a positive correlation with all flow properties.

2. Pore structure characterised by AOS values have weak correlation with all the flow properties whereas volumetric pore characteristics represented by MR25, MDR, and PSDP display a very strong association ($\tau \geq 0.75$) with all the hydraulic properties

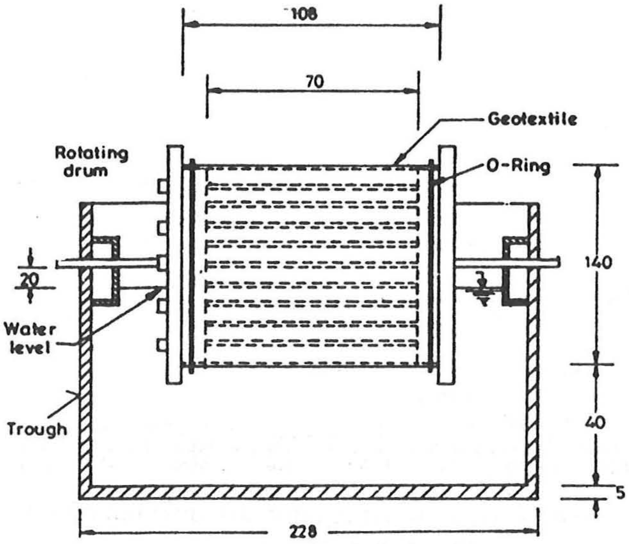

Fig. 1 Principal features of hydrodynamic sieve apparatus (after Pradhan, 1993)

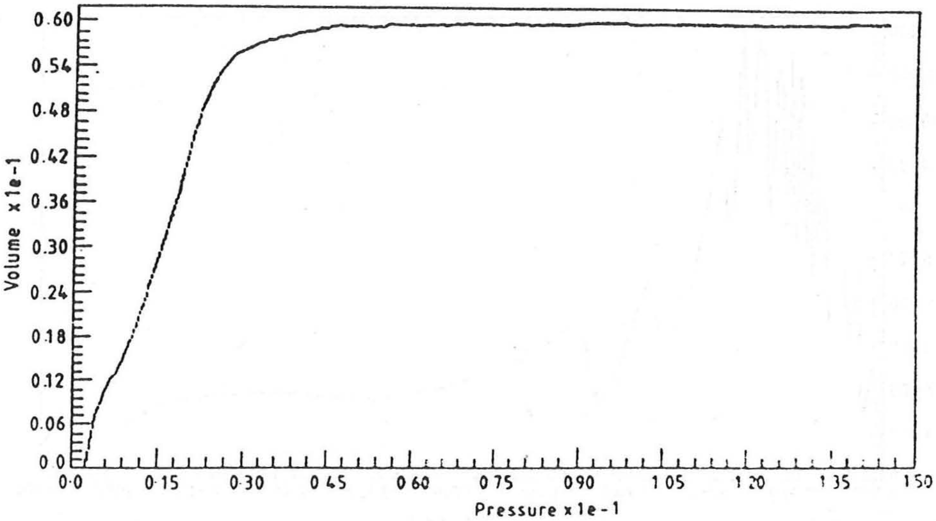

Fig. 2 A typical plot of pressure versus cumulative pore volume (after Dey, 1995)

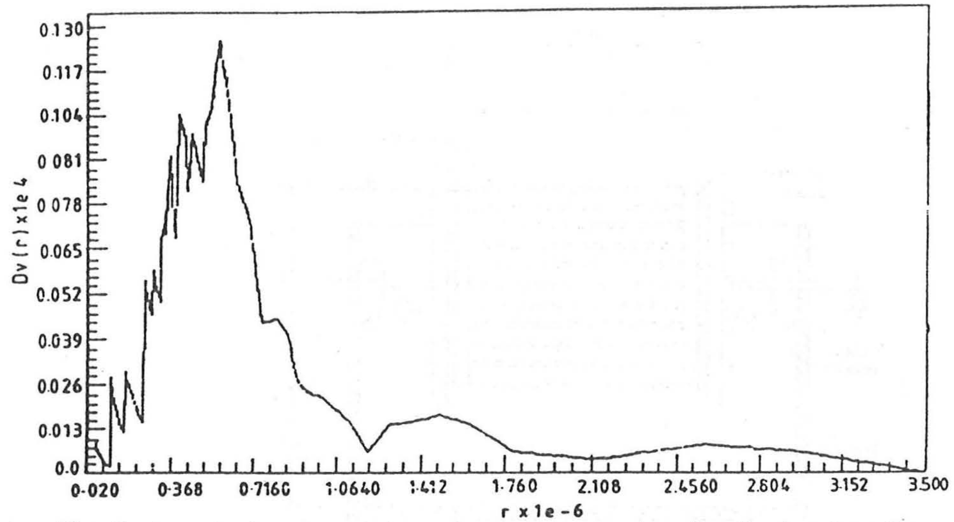

Fig. 3 A typical curve of the volumetric pore size distribution function (after Dey, 1995)

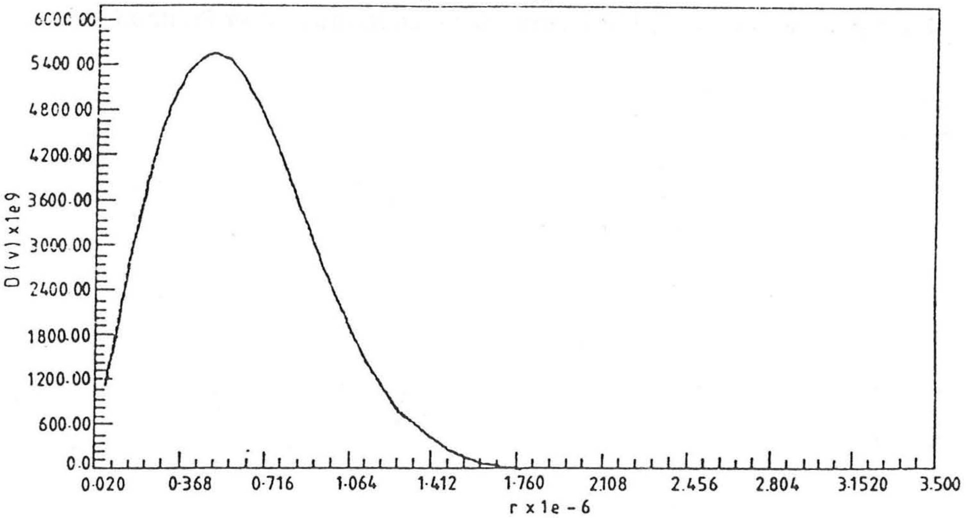

Fig. 4 A typical fitted distribution curve with the experimental data

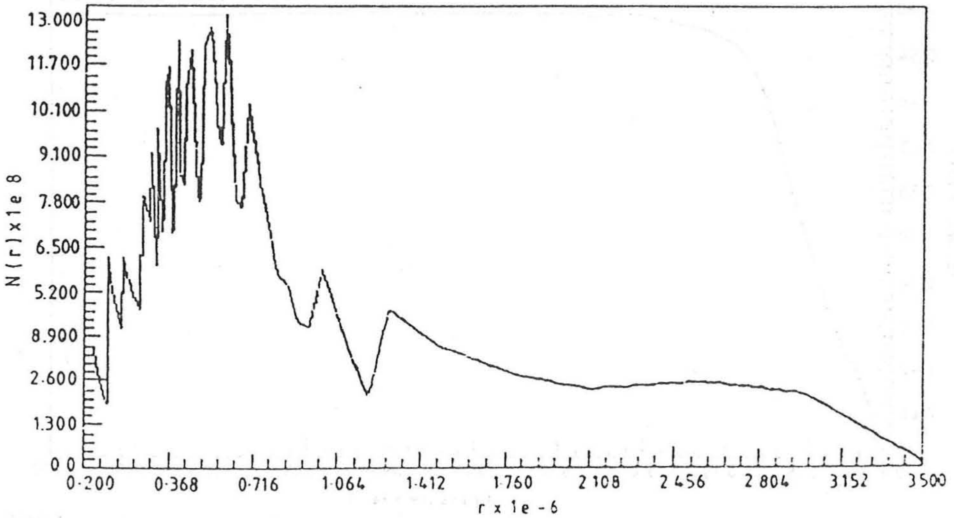

Fig. 5 A representative distribution curve for number of pores versus pore size

of both polyester and polypropylene geotextiles. This recalling the fact that apart from large pores the flow through a geotextile is also governed by the smaller as well as tortoise pores whereas AOS is the representation of the largest through and through pore present in geotextile. A change in the AOS value, while affecting the flow behaviour of a geotextile, does not imply a proportionate change in other pores.

3. For polyester fabrics the degree of association of AOS with other properties is weaker than that of polypropylene geotextiles owing to the uncertainity associated in estimation of AOS of fabrics having smaller pores.

4. Among the volumetric pore size characteristics, PSDP has very consistent and a strong relation with all hydraulic properties, where as MR25 and MDR have a comparatively stronger relation with flow properties of polyester and polypropylene geotextiles respectively.

5. Both volumetric pore characteristics and AOS of polypropylene geotextiles show stronger relationship with flow properties associated with cross-plane direction that with in-plane direction. But for polyester geotextiles this difference is very narrow.

NATURAL FIBRE GEOTEXTILES

In view of the inadequate information on the engineering characteristics and biodegradability of natural fibre fabrics of jute and coir that are abundantly available in India, an extensive investigation is undertaken (Balan, 1995). The work included an evaluation of -

i) the physical and engineering characteristics of these materials, and the biodegradability behaviour of coir/jute geotextiles in different soil environments,

ii) the comparative performance evaluation of natural fibre strip drains developed, and

iii) the behaviour of coir geotextiles/fibres in reinforcement through laboratory study and that of erosion control throug a field study.

Results of the studies mentioned at (ii) and (iii) have already been published (Venkatappa Rao and Balan, 1994, 1996). Studies on coir fibre reinforcement are included elsewhere in this volume (Venkatappa Rao and Balan, 1997). Details of the work on biodegradability was presented in Venkatappa Rao and Balan (1996) and Balan and Venkatappa Rao (1996). Attention is now drawn to the work carried out on the engineering characterization of the natural fibre fabrics.

Materials studied

Five types of natural fibre fabrics are evaluated:

i) Woven jute - Type A
ii) Woven jute - Type B
iii) Woven coir
iv) Non-woven coir
v) Non-woven coir with HDPE scrim.

General properties

Figure 6 presents photographs/optical microscopic views of the above materials. Their physical properties are summarised in Table 10. One notes that jute fabrics when

Fig. 6 Views of natural fibre fabrics

a) Optical microscope view of woven coir geotextile, X28

b) Optical microscope view of nonwoven coir geotextile, X28
(without scrim)

c) Optical microscope view of nonwoven coir geotextile, X28
(with scrim)

d) Optical microscope view of woven jute geotextile Type A X28

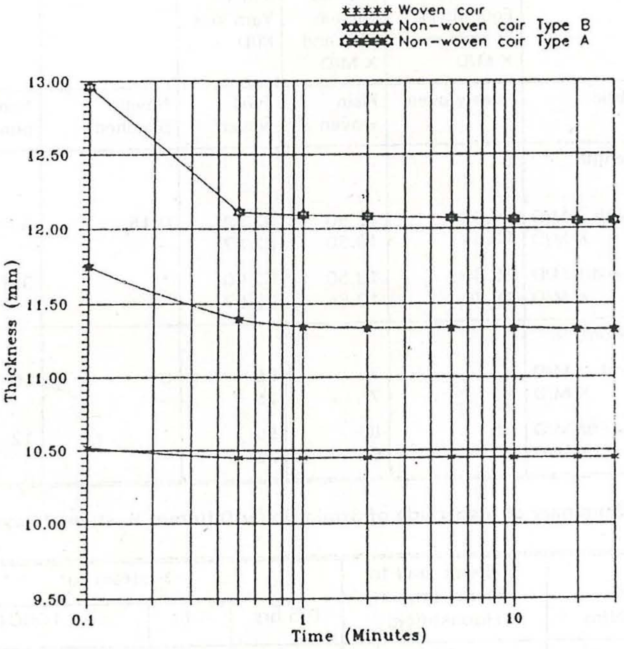

Fig.7 Variation of thickness (mm) with time under a normal pressure of 2 kPa for woven coir and non-woven coir Types A and B.

Table 9 **Estimated co-efficient of correlation values (pearson) of the hydraulic properties of polypropylene fabrics.**

	AOS	CRFLOW	INPLFLOW	MDR	MR25	MR50	MR75	MR95	PPPC2	PPTC2	PSDP
AOS	1.000	--	--	--	--	--	--	--	--	--	--
CRFLOW	0.844	1.000	--	--	--	--	--	--	--	--	--
INPLFLOW	0.566	0.859	1.000	--	--	--	--	--	--	--	--
MDR	0.877	0.934	0.795	1.000	--	--	--	--	--	--	--
MR25	0.876	0.905	0.754	0.943	1.000	--	--	--	--	--	--
MR50	0.690	0.727	0.590	0.791	0.862	1.000	--	--	--	--	--
MR75	0.062	0.177	0.199	0.174	0.277	0.559	1.000	--	--	--	--
MR95	0.340	0.175	-0.029	0.084	0.045	-0.004	-0.020	1.000	--	--	--
PPPC2	-0.760	-0.925	-0.785	-0.886	-0.797	-0.605	-0.159	-0.212	1.000	--	--
PPTC2	-0.525	-0.792	-0.874	-0.737	-0.670	-0.616	-0.342	-0.088	0.807	1.000	--
PSDP	0.787	0.934	0.871	0.918	0.888	0.652	0.117	0.000	-0.849	-0.743	1.000

Table 10 Summary of physical properties of geotextiles tested

Property	Woven jute		Woven coir	Non-woven coir	Non-woven coir with HDPE scrim
	Sample A	Sample B			
Mass per unit area, g/m^2	675	342	1750	900	1350
Thickness at 2 kPa, mm	1.56	1.32	10.45	12.09	11.35
O_{95}, μ_m	--	--	--	1180	420
Mesh size per cm^2	Four, double strands in M/D and Four single strands in X M/D	Four single strands each in M/D and X M/D.	2 Yarns in M/D and 1 Yarn in X M/D	--	--
Type of fabric structure	Plain woven	Plain woven	Twill woven	Needle punched	Needle punched
Tensile strength, kN/m					
- Wide width M/D	24.05	12.60	62.59	0.15	3.49
X M/D	17.58	10.30	22.27	--	--
- Narrow width M/D	25.66	13.50	63.00	*	3.67
X M/D	18.70	10.65	23.07	--	--
Strain at failure, %					
Wide width M/D	10	7	58	6	10
X M/D	10	7	25	--	--
Narrow width M/D	11	8	50	*	12
X M/D	8	6	29	--	--

Table 11 Summary of Magnitude of Strain Under Different Sustained Loads

Applied sustained loading kN/m	% Break load for narrow strip in Hounsefield	% strain for		
		0.5 hrs	1 hr	1000 hr
12.6	20	9.29	9.52	14.40
19.0	30	11.15	11.25	16.40
25.2	40	12.28	13.00	19.07
28.4	45	13.47	13.92	21.72
31.6	50	15.60	16.00	27.00
34.8	55	20.33	21.00	40.20
38.4	61	32.89	33.57	Failed before 1000 hrs
41	65	41.25	41.60	Failed before 1000 hrs

compared polymeric geotextiles are on the higher side in terms of Mass/unit area and rather thin but with lower strength. On the other hand, woven and non-woven coir fabrics are quite heavy - range 900-1750 g/m^2 and thick. However, the strength of coir fabrics is about 2½ times that of the jute fabrics, but with a failure strain in machine direction of over 50%. The non-woven coir is characterized by a very low strength and large O_{95}. It is also interesting to note that the narrow strip tensile strength of woven coir specimens (twelve) ranges from 60 kN/m to 66 kN/m with an average of 63.0 kN/m and coefficient of variation of 3%. Similarly the range in failure strain was 47% - 54% with an average of 50% and coefficient of variation of 5%. The secant modulus however varied from 1.04 kN/m to 1.24 kN/m. For a natural fibre fabric, the yarn of which is primarily made in rural areas as a cottage industry; the variation in the properties are surprisingly smaller than expected. This aspect is emphasized herein to obtain a feel of the materials being dealt with. The following is a systematic presentation of other properties.

Thickness

Thickness of different natural fibre geotextiles has been measured with time. Figure 7 presents the results for coir and Fig. 8 for jute. It is evident that for woven coir geotextile and jute geotextile B no further change occurred beyond 30 sec. On the other hand for both types of non-woven coir and woven jute type A, this situation occurred at about 1 minute. Thus it is concluded that thickness of natural geotextiles is required to be determined at the end of 60 sec. after loading to a normal pressure of 2kPa.

Compressiblity

The variation of ratio of change in thickness to the thickness at 1 kPa is shown against normal pressure is shown in Fig. 9 for the four natural fibre fabrics. It is evident that non-woven coir has maximum compressibility whereas the woven coir has the least. Woven jute is more compressible than woven coir. For the woven fabric, compressibility drastically reduces beyond 6 kPa.

Tensile Strength Behaviour

The tensile strength behaviour of natural fibre geotextiles in machine and X- machine directing was studied at different deformation rates and different aspect ratios. The influence of aspect ratio (from 1 to 8) was studied with 200 mm wide specimens, by varying the length from 25 mm to 200 mm. The influence of width was studied by varying the specimen width from 25 to 200 mm, keeping the length as constant at 100 mm. Tests were also conducted on soaked wovens.

Woven Coir Geotextile

The tensile strength behaviour of natural geotextiles was studied on wide width specimens in both the machine and the cross-machine directions, at different deformation rates and different aspect ratios. The influence of aspect ratio (from 1 to 8) was studied with 200 mm wide specimens, by varying the length from 25 mm to 200 mm. The influence of width on tensile strength has been studied by varying the width of specimens from 25 to 200 mm and keeping a constant length of 100 mm so that aspect ratio varies from 0.25 to 2. Wide width tensile tests were also conducted on soaked specimens.

The tensile stress-strain curves obtained in wide width tensile strength tests are shown in Fig. 10. The tensile strength ranged from 59.50 kN/m to 64 kN/m with a coefficient of variation of 3% for the 8 specimens tested. The failure strain was found to have a range between 55% to 60% with a coefficient of variation of 6%. The secant

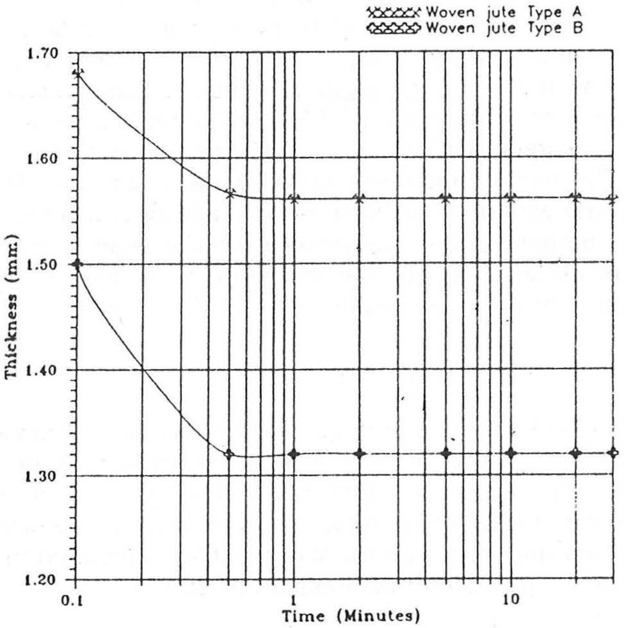

Fig.8 Variation of thickness (mm) with time under a normal pressure of 2 kPa for woven jute Types A and B.

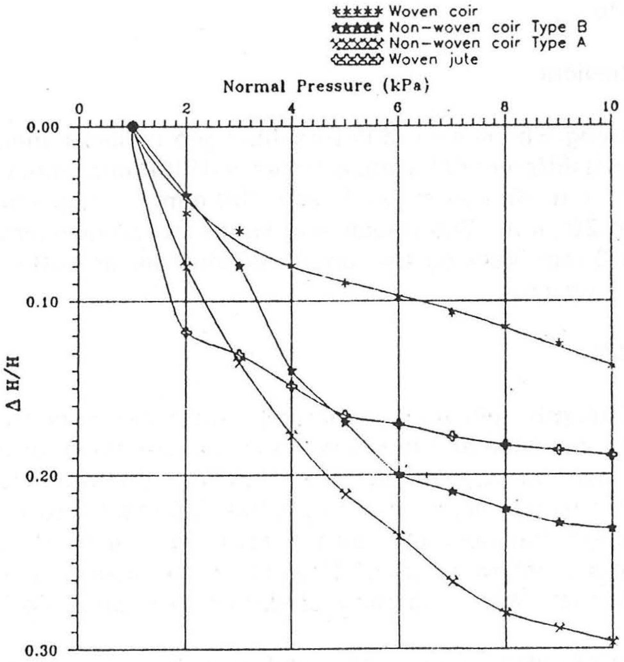

Fig.9 Variation of ΔH/H with normal pressure for natural geotextiles.

modulus is in the range from 0.98 kN/m to 1.15 kN/m. These results further indicate, despite the variation that could be expected in a natural material, there is a fair level of uniformity in the specimens.

For comparison purpose the average stress-strain curves obtained from narrow strip tensile strength test, wide width tensile test and wide width test on wet specimens are depicted in Fig. 11. From these, it can be observed that in the machine direction the narrow strip tensile strength is only a little larger (0.8%) than that of wide width. The same behaviour has been observed in the cross-machine direction also, in which the narrow strip tensile strength was 4.5% higher than that of the wide width. As evident from the figure, in the cross-machine direction woven coir has only a smaller strength and failure strain compared to those in the machine direction. This obviously depended on the yarns used and the type of weaving.

In the wet condition, the strength was found to reduce by 36% and the failure strain to increase by 21% when compared with those of dry specimen.

Influence of deformation rate

Figure 12 shows the stress-strain curves for wide width specimens of woven coir geotextile at different deformation rates. No variation is discernible between the curves. For clarity, the variation of tensile strength and failure strain with deformation rate is plotted in Fig. 13. From this figure, it is evident that deformation rates in the range of 2 mm/min to 300 mm/min have no significant influence on the tensile strength and failure strain. For rates less than 2 mm/min, both the strength and failure strain are found to decrease and for rates higher than 300 mm/min, the strength is found to be a little larger.

These results make natural geotextile some what different from synthetic ones.

Influence of aspect ratio

The influence of aspect ratio by changing width/length of specimen on tensile strength and failure strain of woven coir geotextile is given in Fig. 14. In the figure, the continuous line shows the variation in tensile strength and failure strain with aspect ratio by changing width(aspect ratios from 0.25 to 2), whereas the broken line shows those by changing length (aspect ratio from 1 to 8). It can be observed from the figure that the tensile strength with aspect ratio shows no specific trend. The average strength for different aspect ratios is between 58 kN/m to 63 kN/m. In both the aspect ratio range (0.25 to 2 and 1 to 8), one parameter (length/width) of the wide strip tensile test specimen is kept constant. Hence by comparing with the tensile strength of wide width, the tensile strength is found to vary in a range of +0.8% to -7%. Since the variation from wide strip tensile strength is less than 10%, it can be concluded that the ratio of width to length of the specimen does not have any influence on the tensile strength within the range tested.

Similarly, from the figure, it is evident that the failure strain remained almost constant when the width of specimen changed keeping the length constant. When the length of specimen changed, keeping width constant, the failure strain seems to have a linear variation. This may be because, coir being an extensible material, under very small length, it elongates more than double the original size before failure, or it may be due to the gripping of the same fibres, at both ends at a closer spacing, of each yarn in the fabric.

By changing the width of specimen, it was also observed that the increase in number of yarns did not directly influence the failure strength. For example, a single coir yarn had a strength of 275 N while, a 100 mm x 50 mm wide specimen (aspect ratio 0.5) having 15

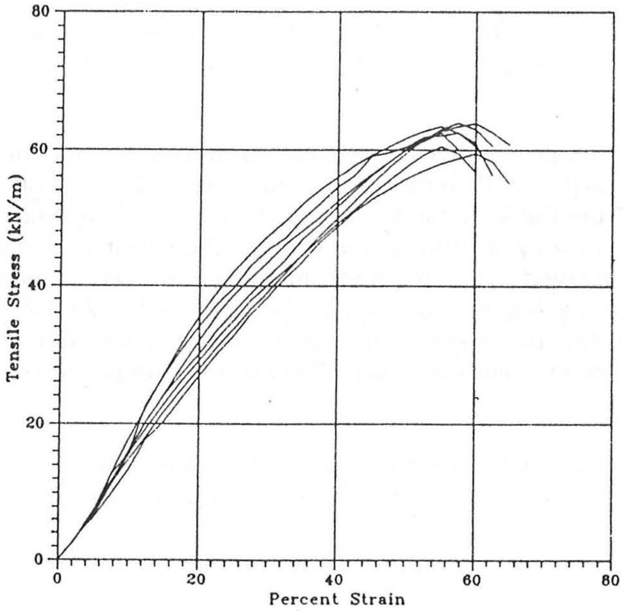

Fig.10 Wide strip tensile stress-strain curves for woven coir geotextile in machine direction.

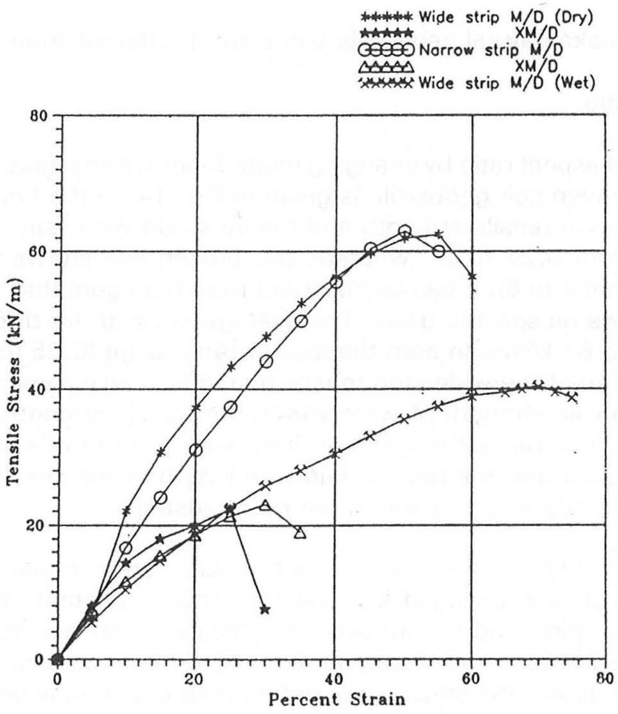

Fig.11Tensile stress-strain curves for woven coir geotextile.

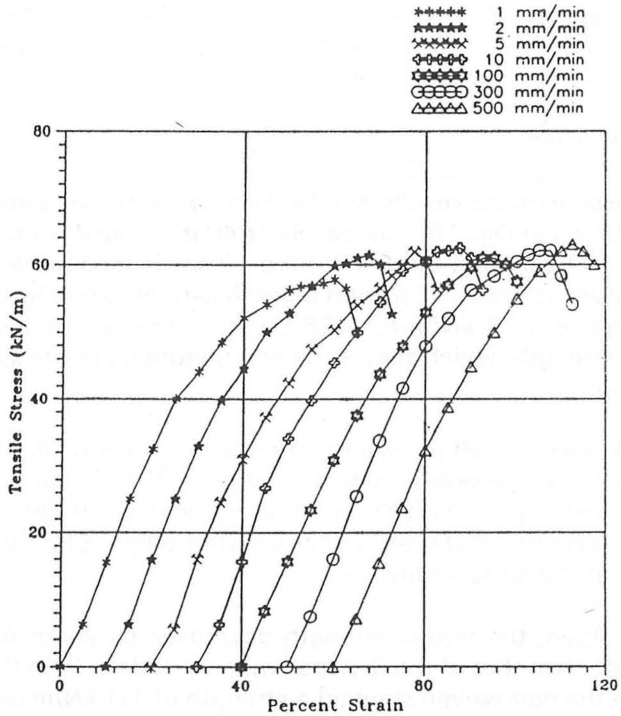

Fig.12 Typical wide strip tensile stress-strain curves at different deformation rates for woven coir geotextile in machine direction.

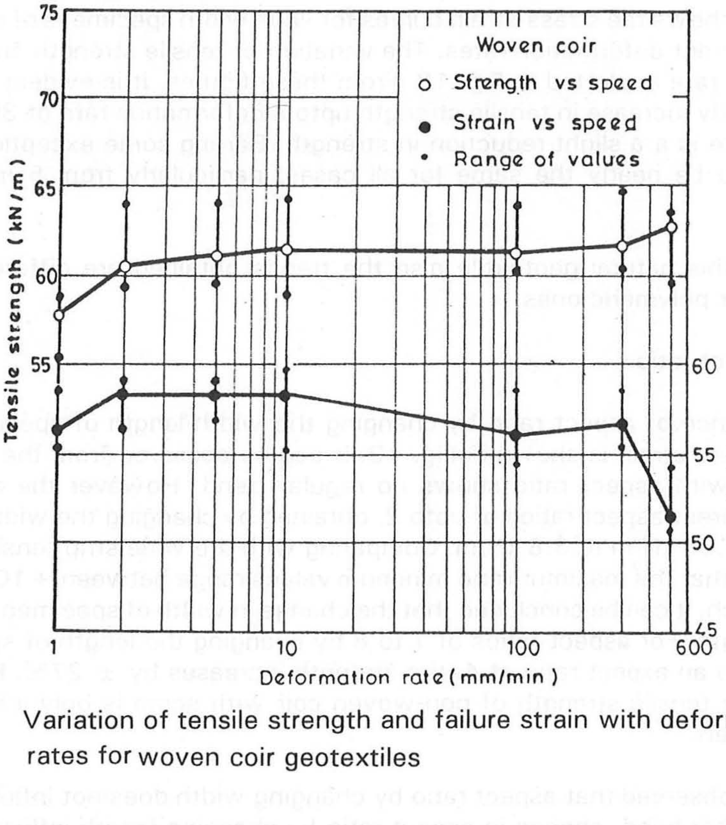

Fig. 13 Variation of tensile strength and failure strain with deformation rates for woven coir geotextiles

yarns has only a strength of 3001 N instead of 15 x 275 N, ie. 4125 N. The strength obtained was thus only 72% of 4125 N. For other aspect ratios, the strength obtained was between 71% to 75% of total yarn strength.

Non-woven Coir Geotextiles

The tensile stress-strain curves obtained in wide width tensile strength tests for Type B coir geotextile are shown in Fig. 15. The tensile strength ranged from 2.80 kN/m to 4.50 kN/m with a coefficient of variation of 15% for the 13 specimens tested. The failure strain was found to range between 8% to 12% with a coefficient of variation of 14%. The secant modulus is in the range of 0.75 kN/m to 1.25 kN/m. These results indicate a significant variation in the tensile strength, which shows the non-uniformity of the specimens from non-woven fabric with scrim.

Average of all values, which gives a coefficient of variation within 10% are taken to plot the average stress-strain behaviour shown in Fig. 16. It includes the results of narrow strip tensile test, wide width test in wet/dry conditions and that of HDPE scrim in wide width test. In this case also, it is observed that the narrow strip tensile strength is only marginally higher (6%) than that of the wide width.

In the wet condition, the tensile strength decreases by about 61% and the failure strain increases by 30% than that of the dry specimen as evident from the figure. The HDPE sacking retrieved from the non-woven showed a strength of 1.1 kN/m and a failure strain of 4%.

Influence of deformation rate

Figure 17 shows the stress-strain curves for wide width specimens of non-woven coir geotextile at different deformation rates. The variation of tensile strength and failure strain with deformation rate is plotted in Fig. 18. From these figures, it is evident that there is a marginal but steady increase in tensile strength upto a deformation rate of 300 mm/min. At 500 mm/min there is a a slight reduction in strength. Barring some exceptions, the failure strain is found to be nearly the same for all cases, particularly from 5 mm/min to 100 mm/min.

Thus for this natural geotextile also the trends obtained are different from those usually known for polymeric ones.

Influence of aspect ratio

The influence of aspect ratio by changing the width/length of specimen on tensile strength and failure strain is shown in Fig. 19. It can be observed from the figure that the tensile strength with aspect ratio shows no regular trend. However the average tensile strength, for different aspect ratios of upto 2, obtained by changing the width of specimen, varies between 2.95 kN/m to 3.8 kN/m. Comparing with the wide strip tensile test value, it can be observed that the maximum and minimum values range between +10% to -14%. As a general approach, it can be concluded that the change in width of specimen does not affect the tensile strength. For aspect ratios of 1 to 8 by changing the length of specimen, it can be seen that upto an aspect ratio of 4, the strength increases by ± 27%. Hence it can be deduced that the tensile strength of non-woven coir with scrim is only influenced by the length of specimen.

It can be observed that aspect ratio by changing width does not influence the failure strain. On the other hand, change in aspect ratio by changing length influences the failure

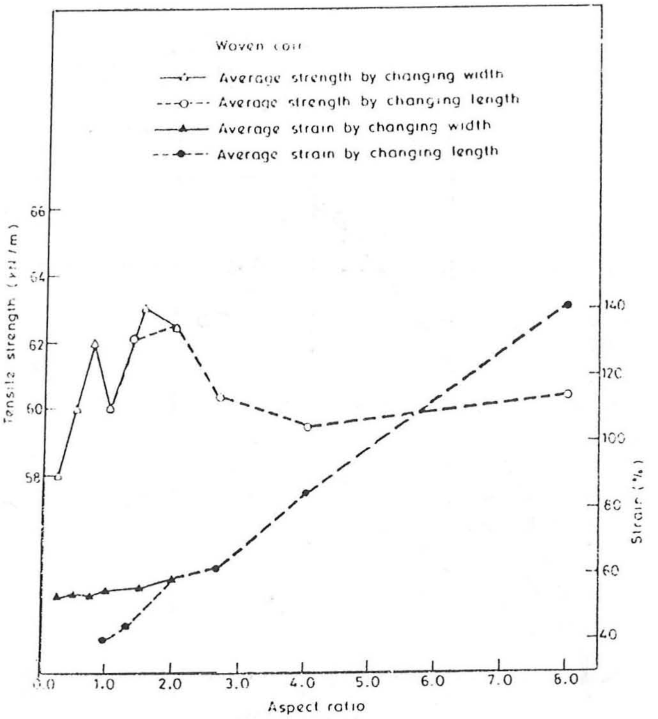

Fig. 14 Variation of tensile strength and failure strain with aspect ratio for woven coir geotextiles

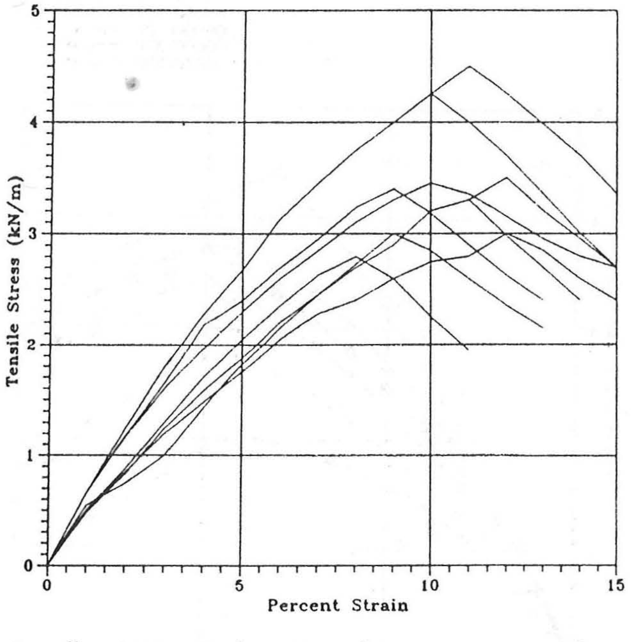

Fig.15 Wide strip tensile stress-strain curves for non-woven coir geotextile with scrim (Type B).

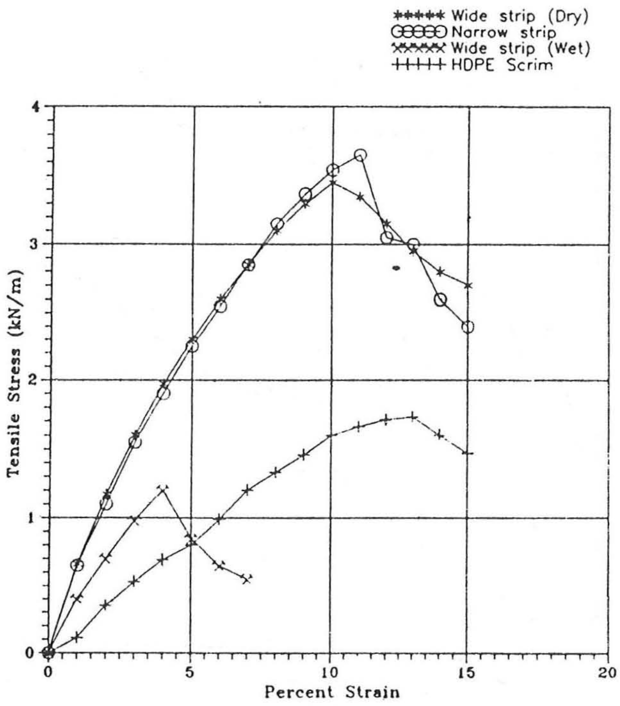

Fig.16 Tensile stress-strain curves for non-woven coir geotextile with scrim (Type B).

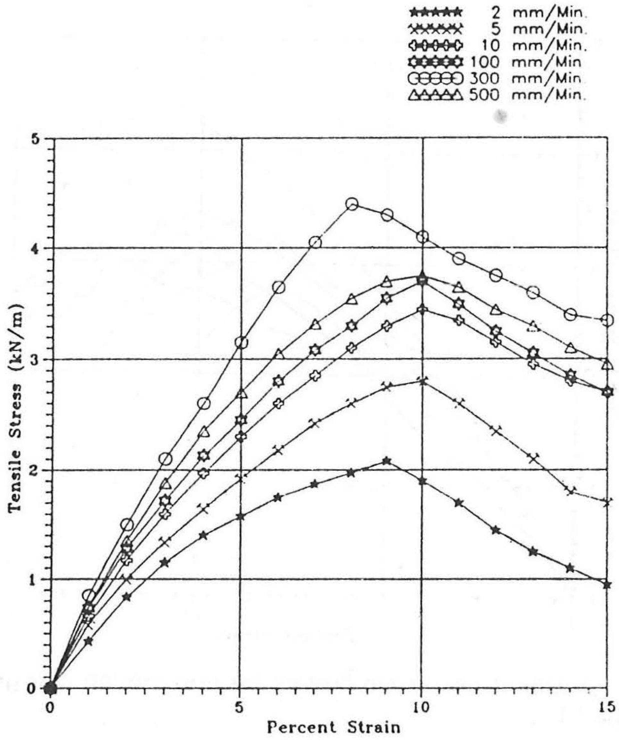

Fig.17 Typical wide strip tensile stress-strain curves at different deformation rates for non-woven coir geotextile (Type B).

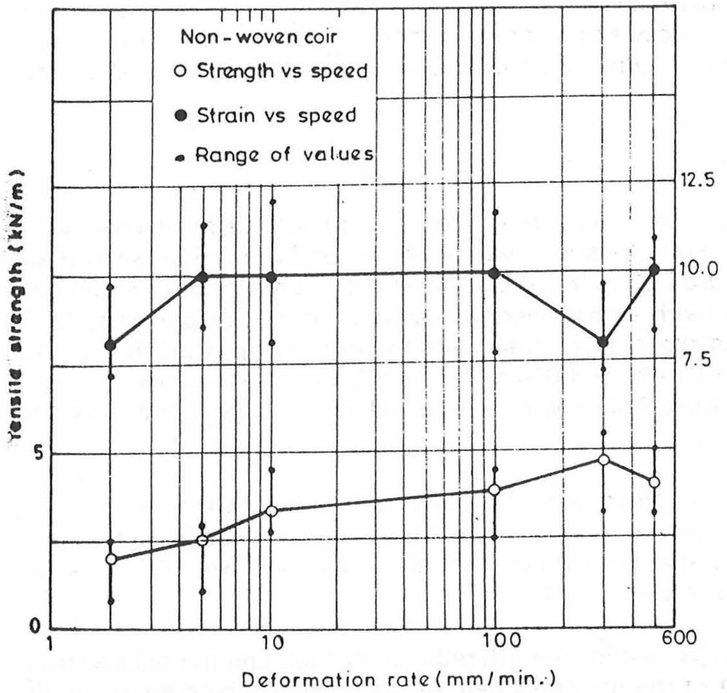

Fig. 18 Variation of tensile strength and failure strain with deformation rates for non-woven coir geotextiles (Type B)

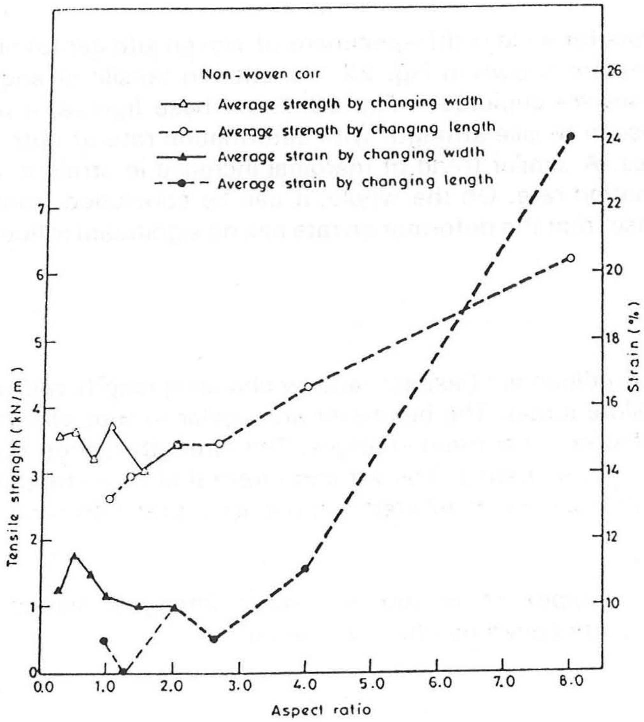

Fig. 19 Variation of tensile strength and failure strain with aspect ratio for non-woven coir geotextiles (Type B)

strain significantly, i.e. the failure strain increases with decrease in length. It may be due to the fact that as length reduces same fibre will be held up at top and bottom grips along with the scrim. However more studies are required to clearly define trends and understand the behaviour.

Woven Jute Geotextile

Figure 20 shows the wide width tensile strength test results on woven jute geotextiles of Type A. From these as well as those for Type B, it is seen that the tensile strength ranges from 20.83 kN/m to 26.50 kN/m (with a coefficient of variation of 8%) and 11 kN/m to 14.5 kN/m (with a coefficient of variation of 8%) respectively for Type A and B. For those two types the failure strain was found to range from 8% to 12% (with a coefficient of variation of 14%) and 6% to 9% (with a coefficient of variation of 13%). The secant modulus range from 0.93 kN/m to 1.56 kN/m for Type A and 1.26 kN/m to 2.18 kN/m for Type B.

The average tensile stress-strain behaviour of different tensile tests on Type A fabric are shown in Fig. 21. It can be observed that the behaviour is similar to that of woven coir. The narrow strip tensile strength values in machine direction were found to be marginally higher than (6.6%) that of wide width.

In wet condition the tensile strength reduces by 15% and the failure strain is doubled when compared to that of the dry specimen. In the cross-machine direction also it can be observed that the narrow strip tensile strength is marginally higher than that of wide width (6%).

Influence of deformation rate

The stess-strain plots for wide width specimens of woven jute geotextile (Type A) for different deformation rates are shown in Fig. 22. Variation in tensile strength and failure strain with deformation rate are depicted in Fig. 23. From these figures, it is evident that there is a marginal increase in tensile strength with deformation rate of upto 100 mm/min, beyond which it decreases. A similar trend of marginal increase in strain is also observed upto 100 mm/min deformation rate. On the whole, it can be concluded from the range of values obtained in each case, that the deformation rate has no significant influence on tensile strength.

Influence of aspect ratio

Figure 24 shows the influence of aspect ratio by changing length/width of specimen, on tensile strength and failure strain. The behaviour are similar to that observed earlier for woven coir geotextile in that no clear trend emerges. The strength ranges from 22.3 kN/m to 26 kN/m for the aspect ratios studied. The variation from that of a standard wide width specimen is ± 8%. As such, it can be concluded that the aspect ratio does not influence the tensile strength.

Failure strain does not appear to be influenced by the change in aspect ratio~~,~~ through change of the width, but is influenced by change of length.

Creep Test

Coir specimens in machine-direction having a width to length ratio of 0.66 were subjected to sustained loads of different magnitudes. The loads applied are 12.6 kN/m to 41 kN/m. These values approximately correspond to 20% to 65% of the in-isolation strip tensile strength values obtained.

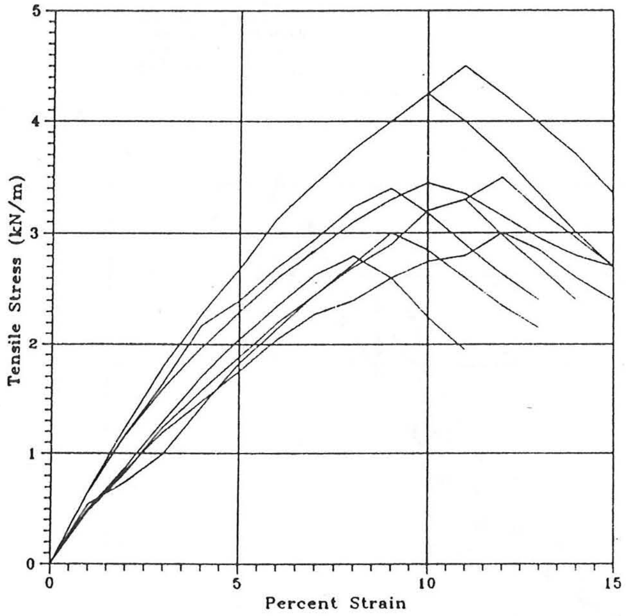

Fig.20 Wide strip tensile stress-strain curves in machine direction for woven jute geotextile (Type A).

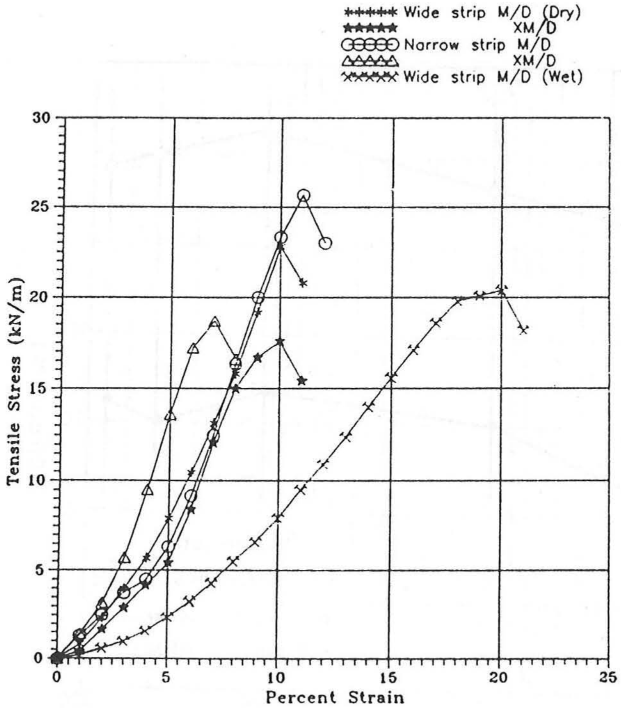

Fig.21 Tensile stress-strain curves for woven jute geotextile (Type A).

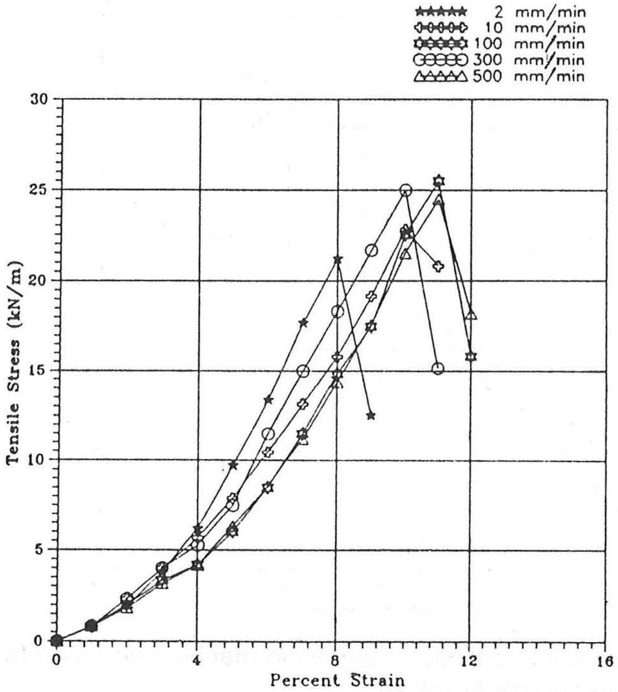

Fig.22 Typical wide strip tensile stress-strain curves at different deformation rates for woven jute geotextile (Type A) in machine direction.

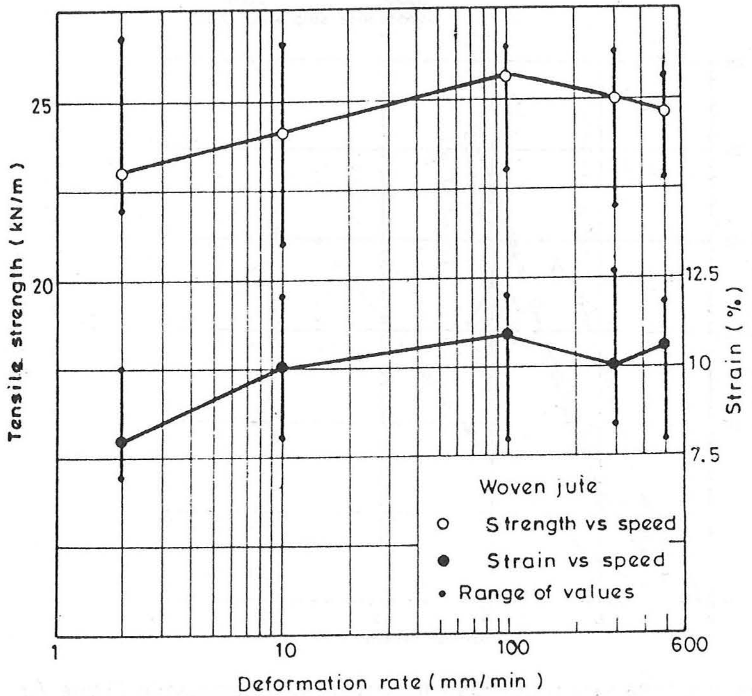

Fig. 23 Variation of tensile strength and failure strain with deformation rates for woven jute geotextile (Type A)

Influence of Time on Strain

The semi-log plots showing variation in strain (%) with time (in minutes) under different load levels are presented in Fig. 25. It clearly indicates that there is an increase in strain with time under sustained loading. It is also evident that the failure strains approach much faster under higher loading. For example a strain of 41.6% is reached after 60 minutes under a load of 41 kN/m while at 34.8 kN/m a strain of only 21% was observed within the same duration.

The magnitude of strains attained at the end of 0.5 hours, 1 hr and 1000 hrs have been tabulated in Table 11 for comparison purposes. It can be seen that even at low loading level of 12.6 kN/m, 9.3% strain is occured within 30 minutes and which is 64.5% of that at 1000 hours.

The variation of strain rate (log) and percent strain under different loadings are presented in Fig. 26. It is seen that the rate of strain decreases with increase in strain and will have a brittle failure.

Effect of magnitude of Loading

The load-strain curves at different time intervals from 0.5 hours to 1000 hours are shown in Fig. 27. At any particular time interval, this figure shows an increase in strain which is more or less linear upto applied loading around 1.34 kN or 25.2 kN/m (40%) beyond which the increase is rapid.

In creep test, it has been observed that there is an increase in strain with time under sustained loading. At very small loading levels, about 10% of strain is produced within 60 minutes of loading while at 65% of static failure load, it was as high as 34%.

All these studies on creep behaviour emphasise clearly that the coir geotextiles possess very low stiffness. Their behaviour is considerably affected even with small loadings within a short duration of time. It has been seen from the in-soil tensile strength tests that the tensile strength improves when embedded in soil. Thus the in-soil creep values may be smaller than the in-isolation values.

Durability

The detailed studies on durability of jute and coir are reported previously. For the sake of continuity in understanding the overall behaviour of these geotextiles, Fig. 28(a) and (b) present the reduction in strength of jute and coir woven fabrics when submerged in a kaolinite slurry. The longer life of coir is evident. However, the life of jute is long enough for use in drainage function like that required by prefabricated strip drain.

CONCLUSIONS

From the results presented in this paper, the following conclusions can be drawn:

1. The rotating type hydrodynamic sieving test apparatus having an optimal working cycle speed of 20 rpm and a test duration of 1500 cycles for a fractioned spherical glass beads of 50 g, provides O_{95} values very much close to the dry sieving test method. This method has an advantage of elimination of the electrostatic charges and simulation more closer to the field condition. Moreover, use of simple equipment

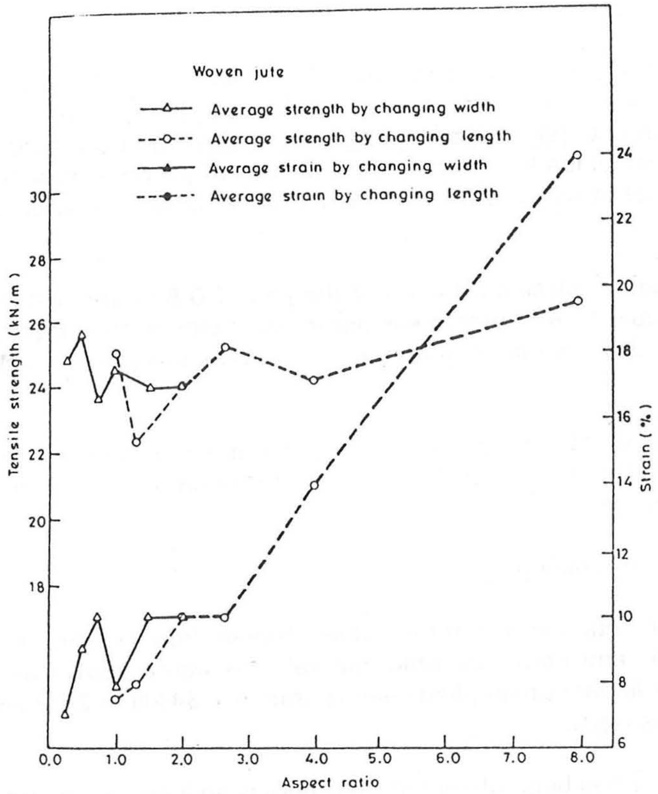

Fig. 24 Variation of tensile strength and failure strain with aspect ratio for non-woven jute geotextiles (Type A)

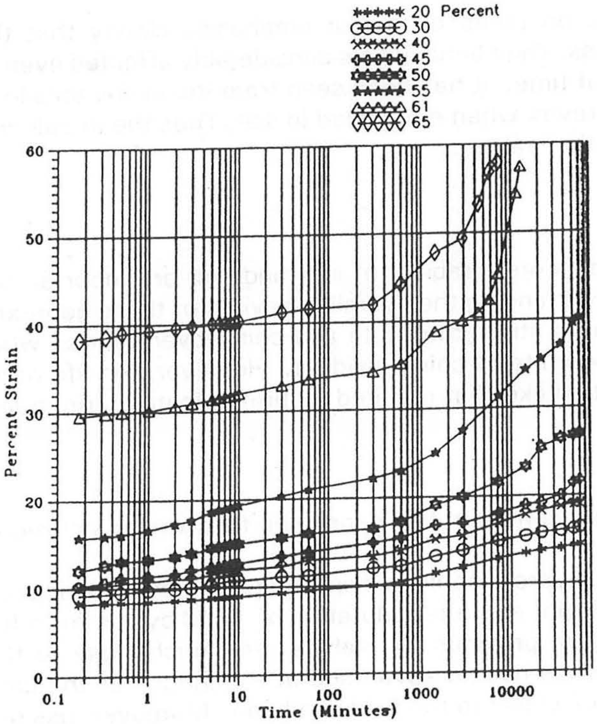

Fig.25 Variation in strain with time under different load levels from creep test.

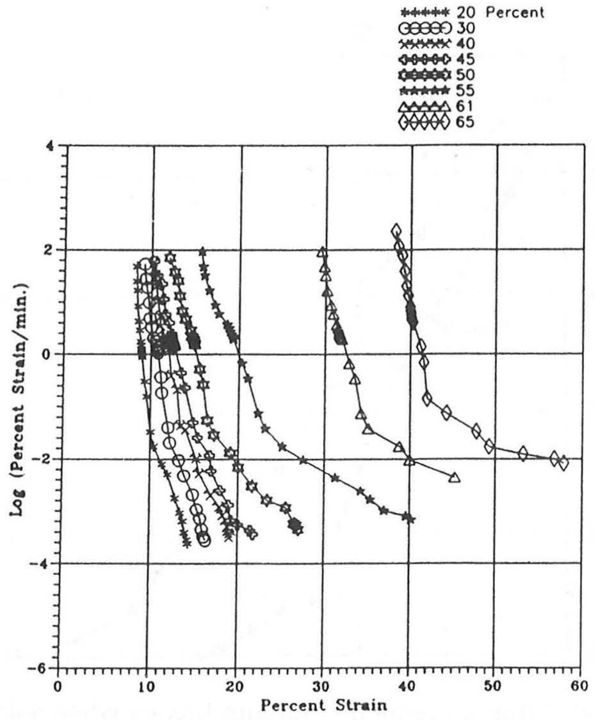

Fig.26 Variation of strain rate with strain at different load levels.

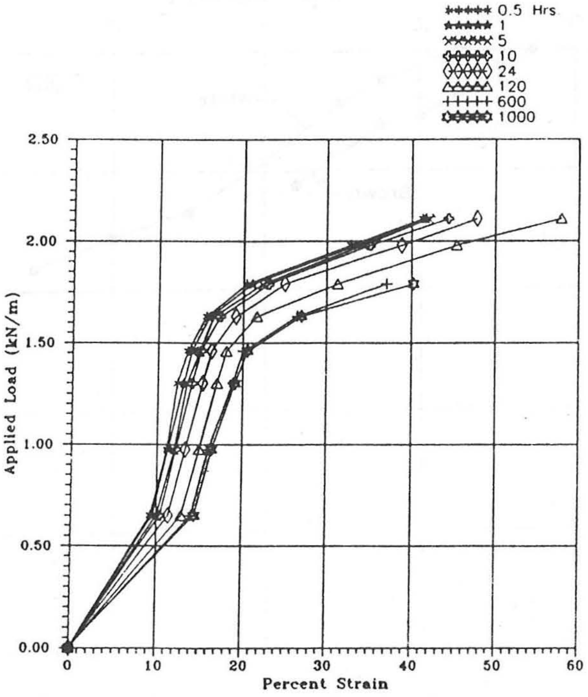

Fig.27 Isochronous curves at different time intervals from creep tests.

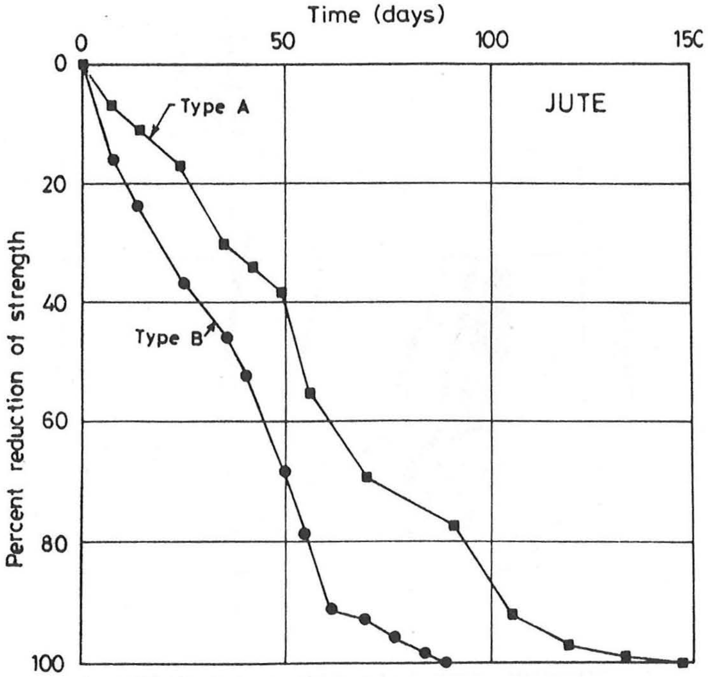

Fig. 28(a) Strength reduction for jute fabrics when submerged in soft saturated clay

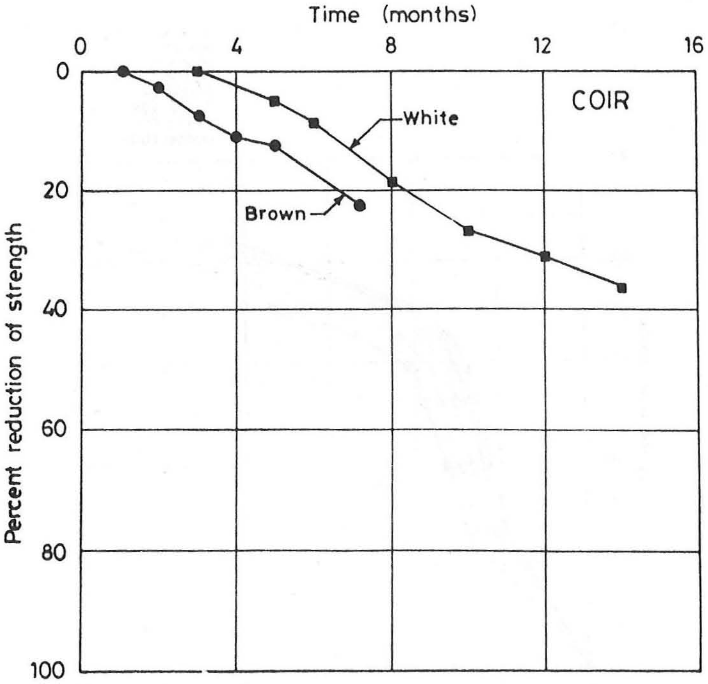

Fig. 28(b) Strength reduction for coir when submerged in soft saturated clay and the duration of test of 75 minutes is the main advantage of the rotating type hydrodynamic sieving test as compared to 24 hour test duration proposed in case of reciprocating type hydrodynamic sieving test.

In addition, the renewal of geotextile specimen for each glass bead fraction in the hydrodynamic test provides more representative O_{95} value because of the larger surface tested. It is found that the coefficient of variance of O_{95} value with different replication is less than the dry sieve test method which indicates good reproducibility of the test method.

2. The pore size distribution curve, obtained from mercury porosimetry can be fitted with a standard distribution involving only one parameter (α). From the data one can estimate the number of pores of different pore sizes. Using this data and following the definition of AOS, the mean pore radius MR95, MR75, MR50 and M25 can be calculated. Numerically MR25 values exhibit close resemblance to AOS value.

3. Whereas the pore size distribution parameter (α) has the strongest correlation to all other hydraulic properties, AOS has shown the poorest association.

4. For natural geotextiles, it is recommended that:

(i) the value corresponding to a normal pressure of 2kPa after one minute of application of pressure,

(ii) the tensile strength of natural geotextiles can be taken as that corresponding to a wide width specimen (200 mm wide x 100 mm long) at a deformation rate of 10 mm/min. determined in a constant rate of extension machine, and

(iii) the overall life of jute and coir can have a life of more than one and two/three years respectively.

ACKNOWLEDGEMENT

The research reported in this Lecture would not have been possible without the enthusiasm and active support extended by Research Scholars, Dr.M.P.S.Pradhan, Dr.K.Balan and Dr. P.K. Dey. Professor P.K. Banerjee, Dr.K.K.Gupta and Dr.J.M.Kate have joined me in pursuing this exciting research. Their whole-hearted support and uninhibited sharing of thoughts is warmly appreciated.

The support extended by M/s AIMIL, New Delhi and M/s Aspinwall & Co., Cochin is thankfully acknowledged.

Through the painstaking efforts and meticulous work of Mr. N. Bhaskar, it was possible to put this paper into a presentable shape.

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