



Geosynthetics:
material characteristics of
geotextiles & geomembranes

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Korean Fiber Society
Seoul, Korea
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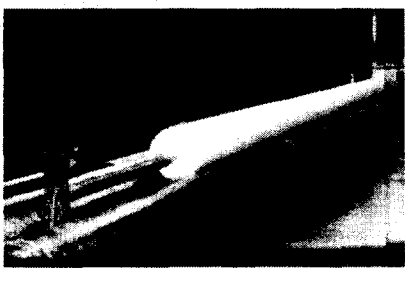


geosynthetics
A manufactured synthetic product used with soil, rock
or other materials
to enhance the performance of geotechnical works

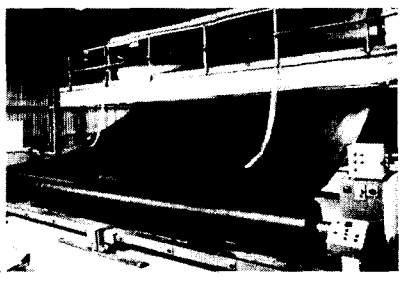
geotextiles
A permeable textile product used in
contact with a soil for separation,
filtration, reinforcement and drainage

geomembranes
A synthetic low permeability material
used as liner in geotechnical applications

Manufacturing of a geotextile



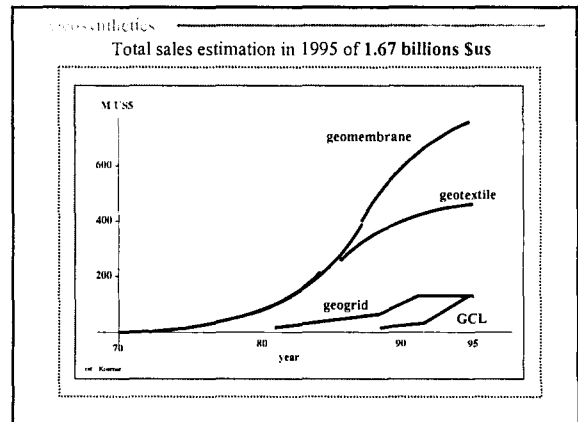
Manufacturing of a geomembrane



The North american market

products	1993	1997	2002
	millions square meters		
geomembranes	58	66	84
geotextiles	333	438	581
geogrids	18	37	58
erosion control	62	98	122
CGL.s	4	11	13
bituminous	0	1	2
others	12	11	21
total	488	662	881

reference : IFAI Market report 1995, GFR June 1997



Geosynthetic characteristics

physicals

manufacturer & product

structure & polymer

roll or panel dimensions

thickness , mass & weight

Geosynthetic characteristics

mechanicals

tensile resistance (strength & elongation)

friction angle

puncture resistance

bursting resistance

creep

load resistance

Geosynthetic characteristics

hydraulics

permeability

transmissivity

pore size

gas diffusion

Geosynthetic characteristics

durability

UV resistance

Clogging (mineral & bacterial)

temperature

chemical resistance

micro-organismes resistance

hydrolysis and oxidation resistances

roots resistance

creep resistance

Geotextiles

The functions

separation

reinforcement

filtration

drainage

puncture protection

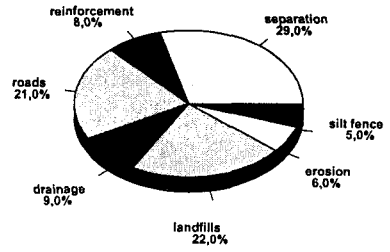
container

North American market (in millions square yards)

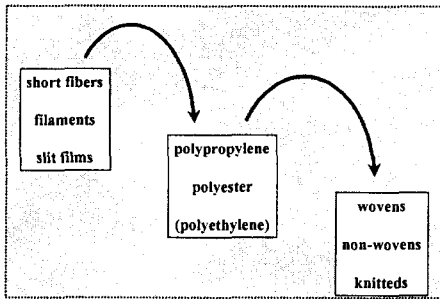
application	1992	1993	1995	2000	%
separation	105	110	118	175	29
paved roads	102	102	107	123	21
"lining"	65	74	80	131	22
drainage	43	44	46	55	9
reinforcement	20	26	30	47	8
erosion	19	22	24	33	6
silt fence	19	20	23	32	5
total	373	398	428	596	

From source: F&A Market Report, 1998

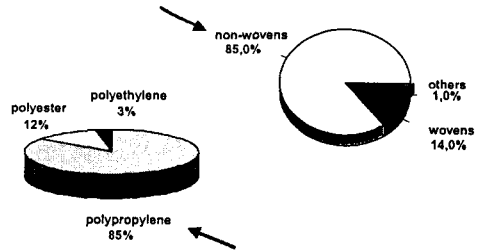
Applications share (in 1995)



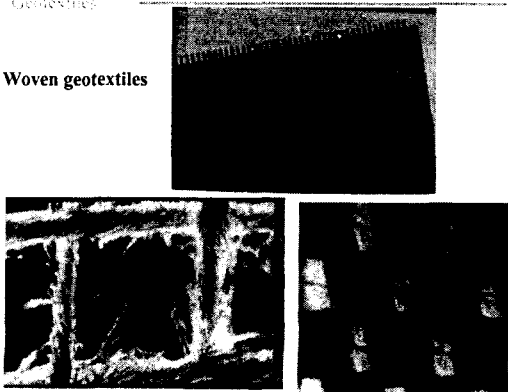
The products



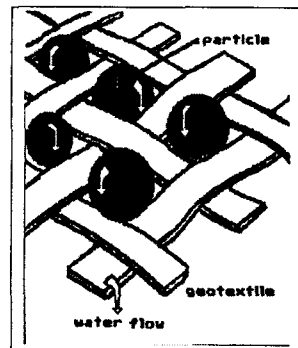
Market share in 1995



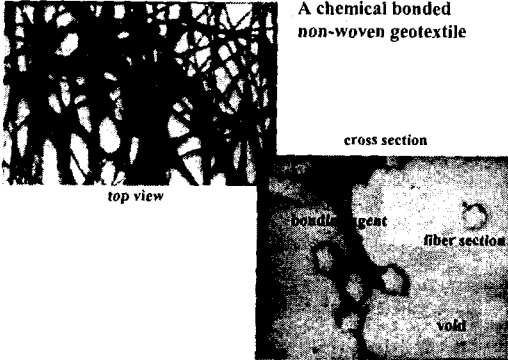
Woven geotextiles



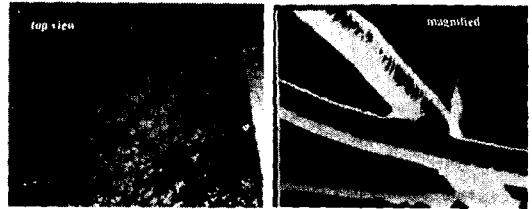
Slit film geotextile



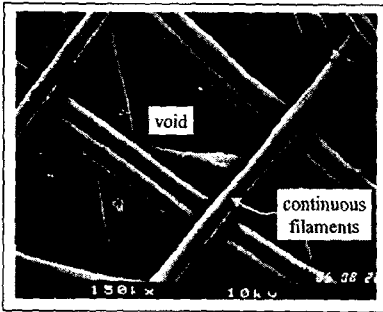
A chemical bonded non-woven geotextile



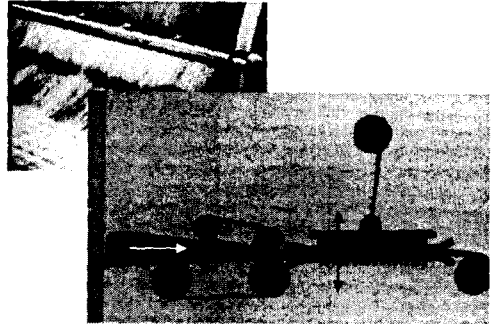
A heat bonded non-woven geotextile



A magnified top view of a heat bonded non-woven geotextile



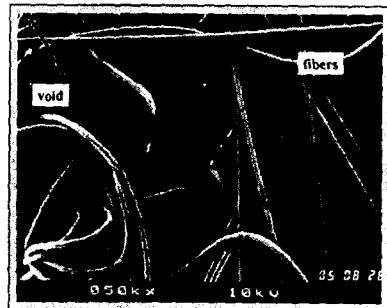
Manufacturing of a needle-punched non-woven geotextile



Needling equipment for needle-punched non-woven geotextile



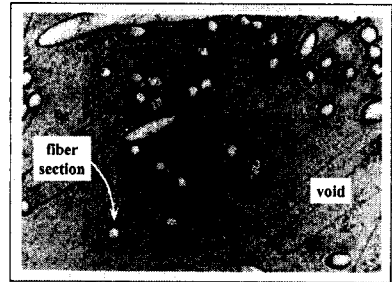
A magnified top view of a needle non-woven geotextile



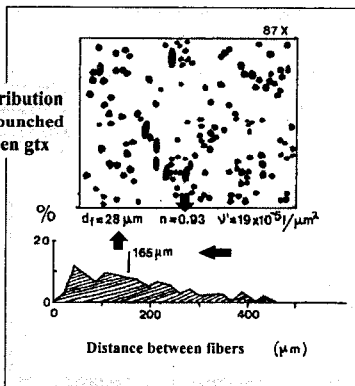
A magnified cross view of a needle-punched non-woven geotextile at needling hole



A cross section of a needle-punched non-woven gtx



fibers distribution in needle-punched non-woven gtx



Applications

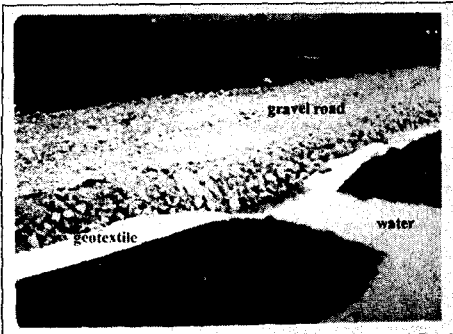
Geotextile applications

- highways and railways
- separation between soft soils and granulars
- drainage systems
- ponds, reservoirs & basins
- erosion control: canals, sea coasts, ...
- slope protection
- silt fences

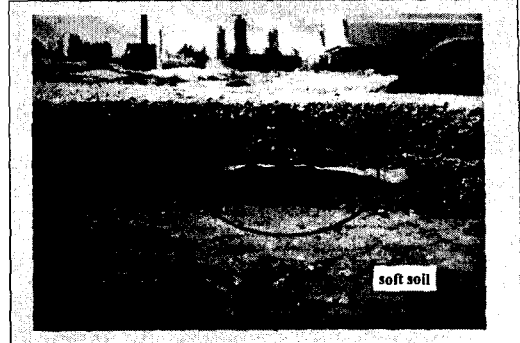
An access road: reinforcement



An access road: reinforcement and separation



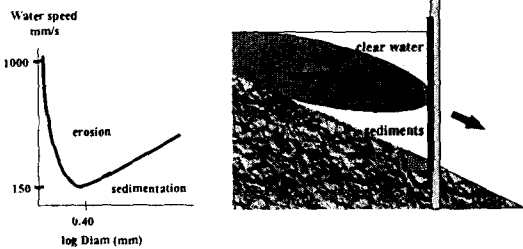
Temporary road: separation



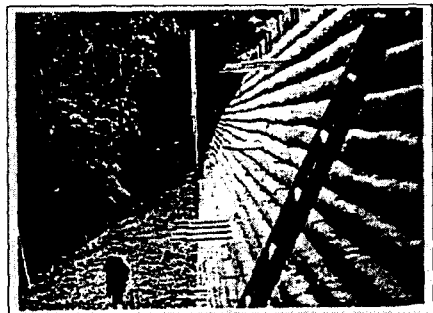
A silt fence: fines retention during construction



Mechanism for silt fence



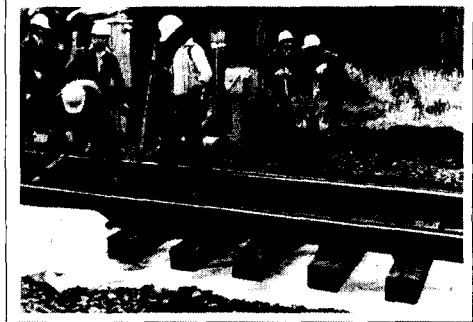
Reinforced wall with geotextile



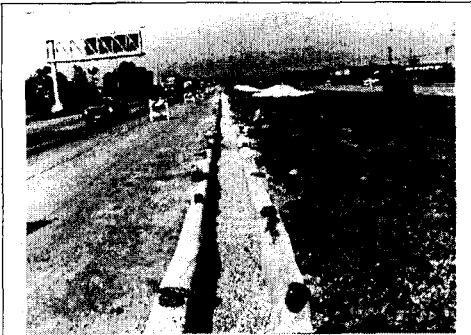
Reinforced wall with GTX and gabions



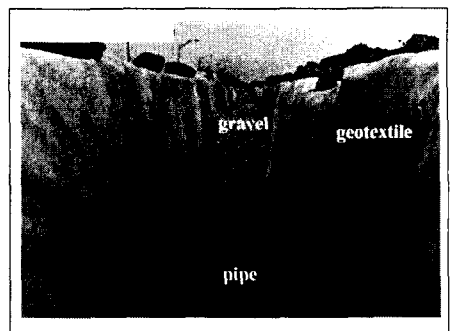
Railroad rehabilitation: reinforcement & separation



A highway trench for drainage



Drainage trench in construction



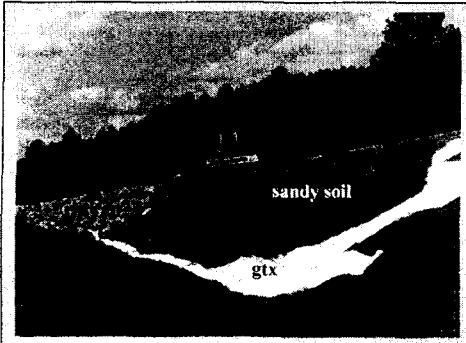
Trench in construction: separation



Beach erosion



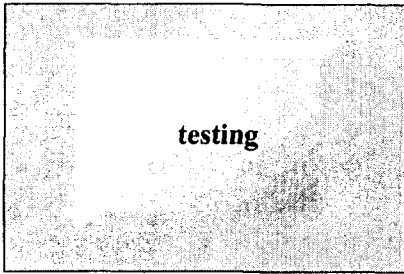
Slope stabilisation



Paved highway rehabilitation



testing



Relevance of gtx characteristics to functions

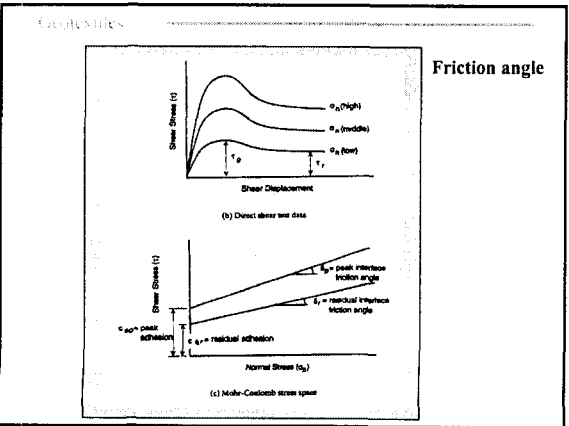
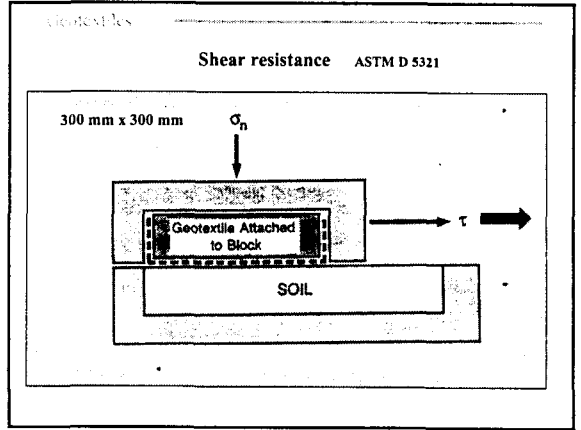
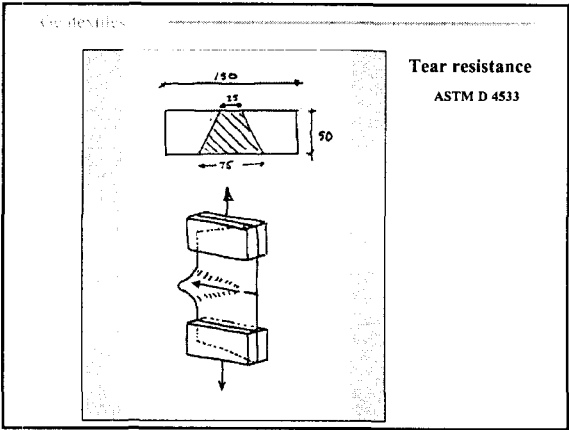
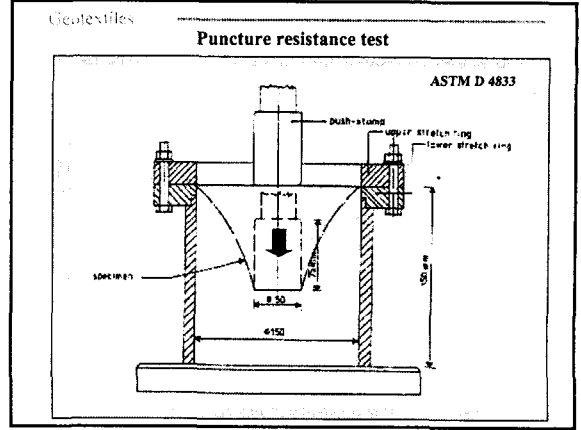
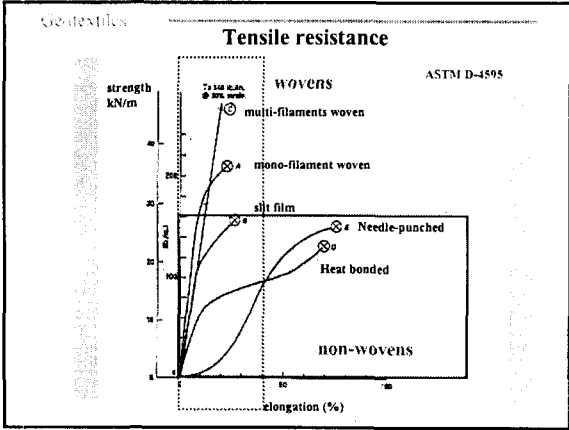
property	reinforcement	drainage	filtration	separation	container
mass		✓	✓		
thickness		✓	✓	✓	
Tensile resistance	✓			✓	✓
Tear resistance	✓		✓	✓	✓
Impact resistance	✓		✓	✓	✓
Abrasion resistance				✓	
Friction angle	✓				✓
permeability		✓	✓	✓	✓
wettability		✓	✓		
Filtration opening size		✓	✓	✓	

ASTM tests, guides and practices for geotextiles

- D1987-95(2002) Biological Clogging of Geotextile or Soil/Geotextile Filters
- D4354-99 Sampling of Geosynthetics for Testing
- D4355-02 Deterioration of Geotextiles by Exposure to Light, Moisture and Heat in a Xenon Arc Type Apparatus
- D4491-99a Water Permeability of Geotextiles by Permittivity
- D4533-91(1996) Trapezoid Tearing Strength of Geotextiles
- D4594-96 Effects of Temperature on Stability of Geotextiles
- D4595-86(2001) Tensile Properties of Geotextiles by the Wide-Width Strip Method
- D4632-91(1996) Grab Breaking Load and Elongation of Geotextiles
- D4716-01 the (In-plane) Flow Rate per Unit Width and Hydraulic transmissivity
- D4751-99a Determining Apparent Opening Size of a Geotextile
- D4833-00e1 Index Puncture Resistance of Geotextiles
- D4873-02 Guide for Identification, Storage, and Handling of Geosynthetic Rolls
- D4884-96 Strength of Sewn or Thermally Bonded Seams of Geotextiles
- D4886-88(2002) Abrasion Resistance of Geotextiles (Sand Paper/Sliding Block Method)

ASTM tests, guides and practices for geotextiles (continued)

- D5101-01 Measuring the Soil-Geotextile System Clogging Potential by the Gradient Ratio
- D5141-96(1999) Filtering Efficiency and Flow Rate of a Geotextile for Silt Fence
- D5262-02a Evaluating the Unconfined Tension Creep Behavior of Geosynthetics
- D5261-92(1996) Measuring Mass per Unit Area of Geotextiles
- D5321-02 Determining the Coefficient of Soil and Geosynthetic or Geosynthetic and Geosynthetic Friction by the Direct Shear Method
- D5322-98 Practice for Immersion Procedures for Evaluating the Chemical Resistance
- D5493-93(1998) Permittivity of Geotextiles Under Load
- D5567-94(2001) Hydraulic Conductivity Ratio (HCR) Testing of Soil/Geotextile Systems
- D5819-99 Guide Selecting Test for Experimental Evaluation of Geosynthetic Durability
- D5970-96(2002) Practice for Deterioration of Geotextiles from Outdoor Exposure
- D6241-99 Static Puncture Strength of Geotextiles Using a 50-mm Probe
- D6389-99 Tests to Evaluate the Chemical Resistance of Geotextiles to Liquids
- D6707-01 Circular-Knit Geotextile for Use in Subsurface Drainage Applications
- D6767-02 Pore Size Characteristics of Geotextiles by Capillary Flow Test



Geotextiles

Shear resistance

ASTM D 5321

Interface friction angle ($^\circ$)

	sands			geomembranes			
	Concrete (30 $^\circ$)	Rounded Silty (28 $^\circ$)	Silty (26 $^\circ$)	HDPE smooth	HDPE textured	PVC smooth	PVC textured
Mono-filament woven	26			11		18	20
Woven slit-film	24	24	23				
Heat-bonded non-woven	26						
Needle-punched non-woven	30	26	25	5 to 8	25 to 15	21	23

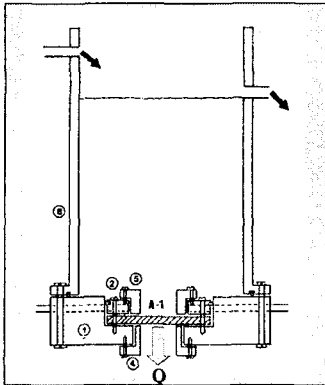
Reference: Rollin 2002 & Koerner 1998

Permeability

ASTM D 4491

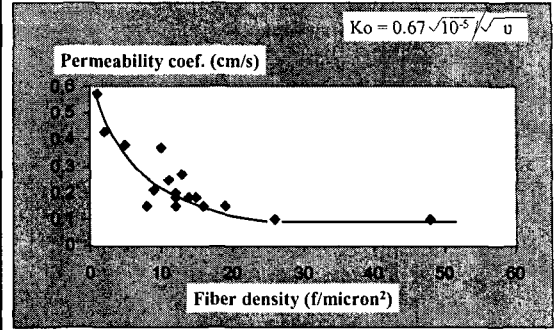
$$K = Q L / A H$$

Q = flow
 L = gtx thickness
 A = flow area
 H = pressure drop

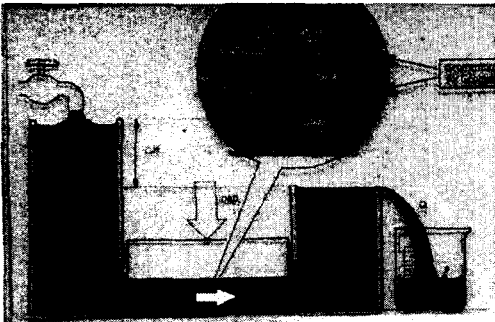


Geotextiles permeability coefficient

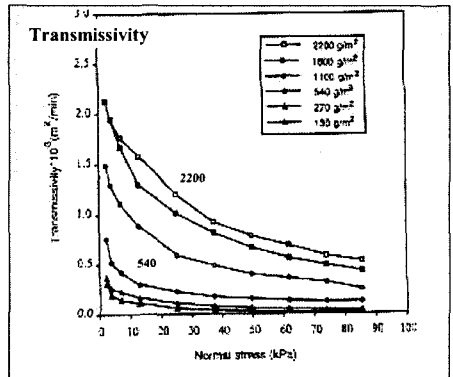
$$K_o = 0.67 \sqrt{10^{-5}} / \sqrt{u}$$



Transmissivity



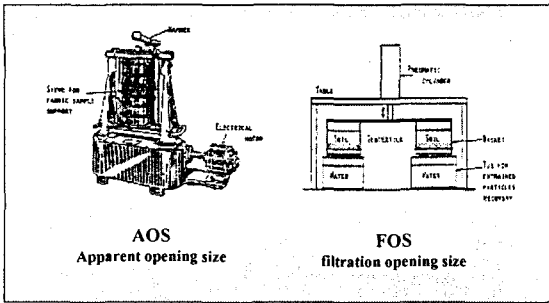
Transmissivity



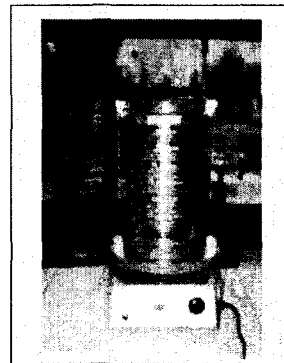
Pore size

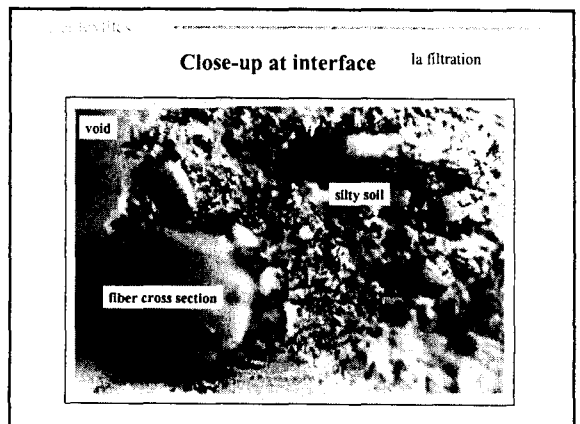
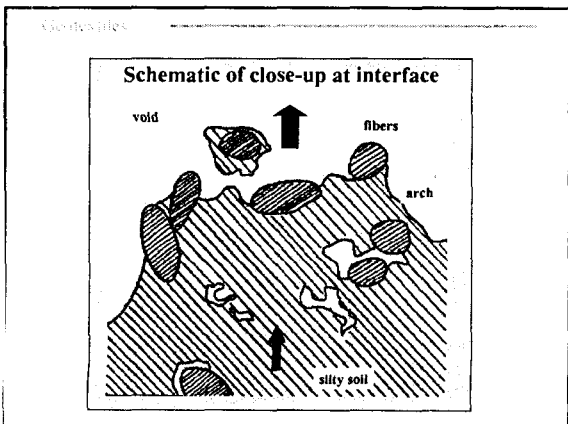
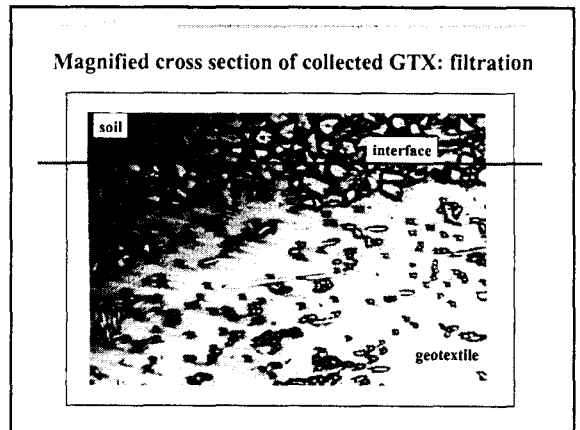
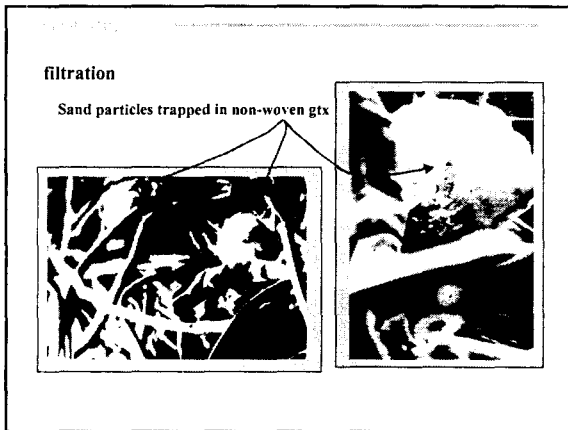
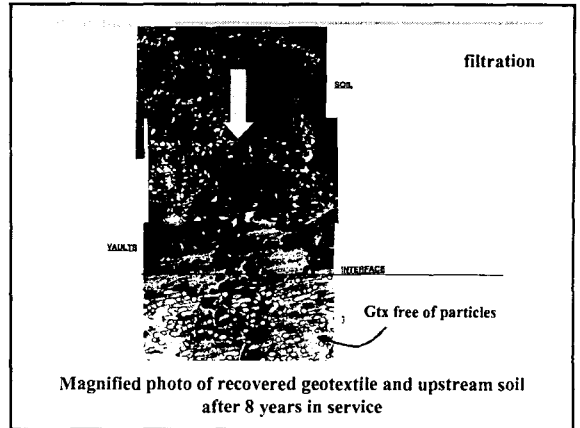
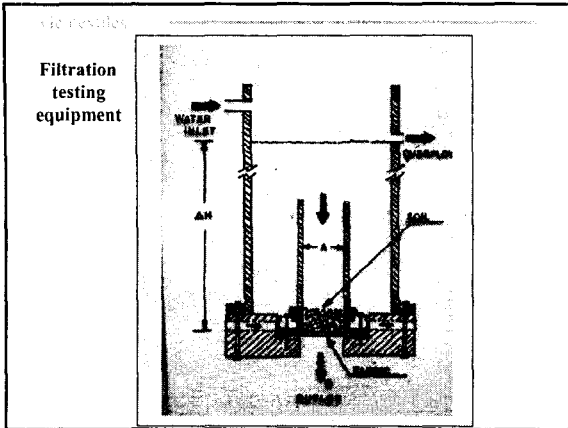
ASTM D4751

CGSB 148.1-10

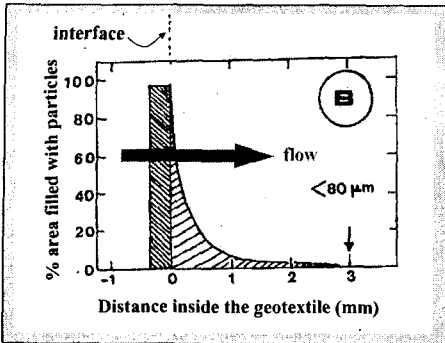


Apparent opening size (AOS) testing equipment

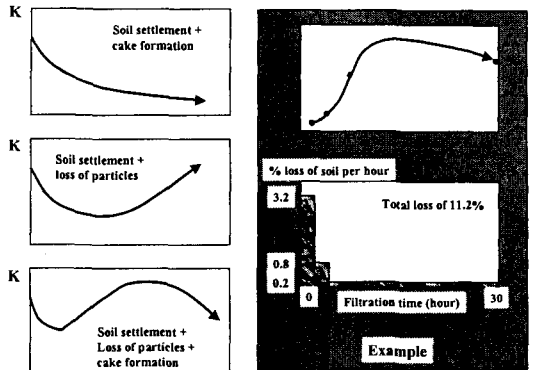




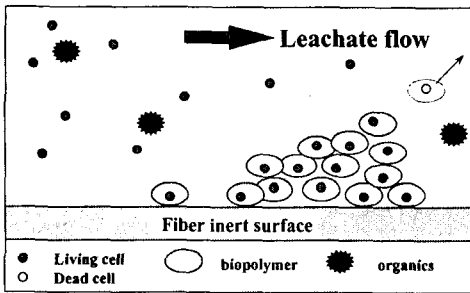
Particles location at cake and inside GTX



Filtration mechanism



Biofilm adhesion to gtx fibers



Biofilm adhesion to fibers

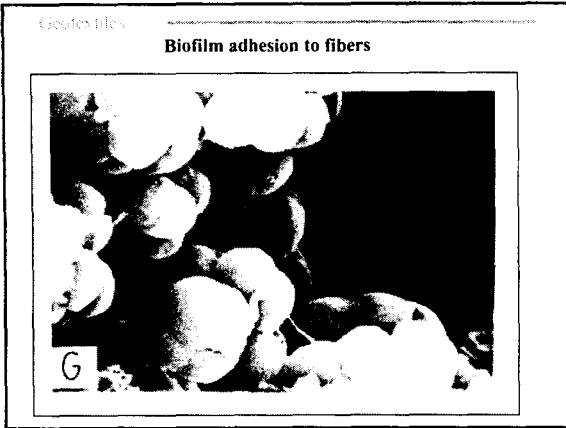


Biofilm adhesion to fibers



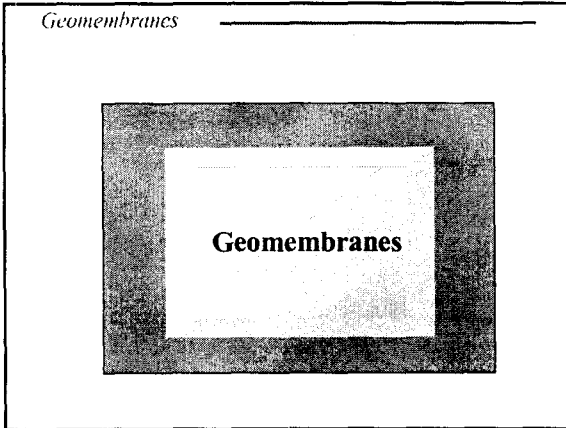
Biofilm adhesion to fibers





Geotextiles

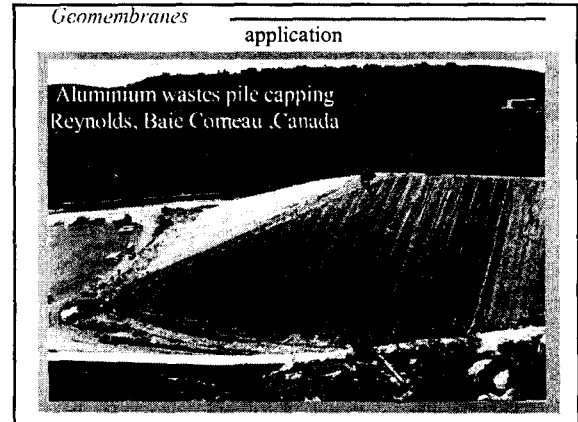
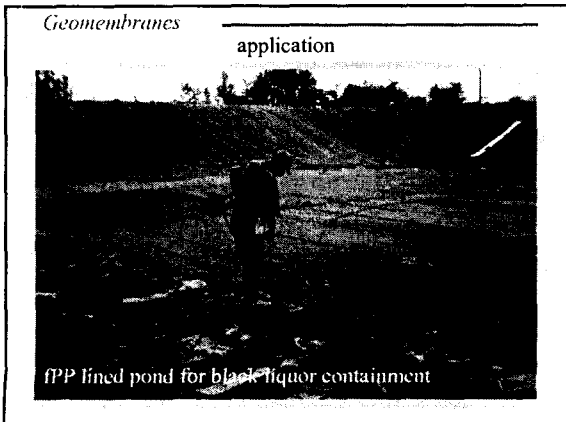
property	units	value		Geotextile characteristics
		minimum	maximum	
mass	g m ⁻²	130	1000	
thickness	mm	0.25	10	
porosity		0.5	0.95	
pore opening	µ	6	12	
tensile resistance	kN m	9	180	
bursting resistance	kPa	350	5000	
puncture resistance	N	45	450	
tear resistance	kN	90	1300	
Impact resistance	J	14	200	
shear(tan gts/tan soil)	%	50	100	
permeability	m s	.00001	.01	
transmissivity	m ² s	0.02	3.3	
pore size	microns	50	2000	



Geomembranes

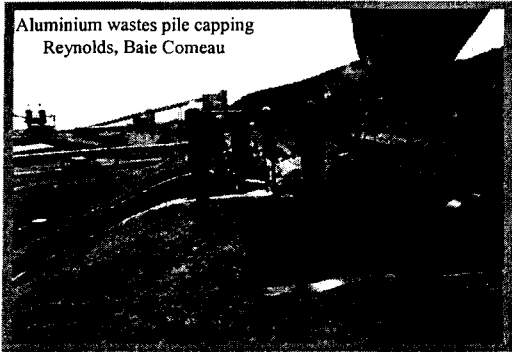
GM: North American market

application	1992	1993	1995	2000	%
MWD	308	308	334	494	52
mining	93	107	114	150	16
toxic wastes	76	76	85	123	13
Drinkable water	35	35	38	48	5
recreational	34	34	35	44	5
canals	19	19	21	26	3
dams	19	19	21	26	3
others	36	22	26	39	3
total	620	620	683	950	

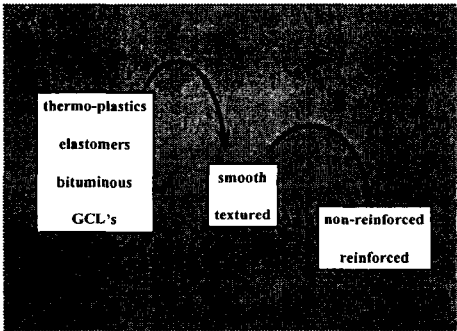
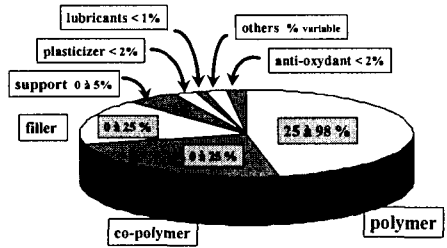


application

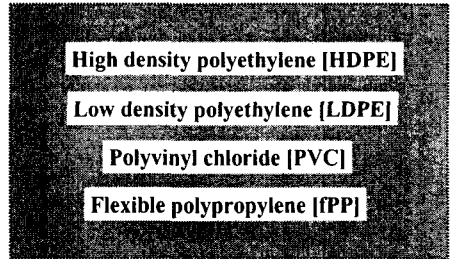
Aluminium wastes pile capping
Reynolds, Baie Comeau



The GM polymeric blend can be a complex recipe

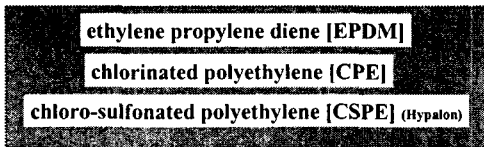


Geomembrane materials
thermo-plastics



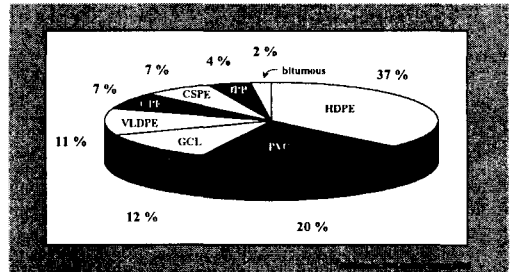
Geomembrane materials (continued)

elastomeric



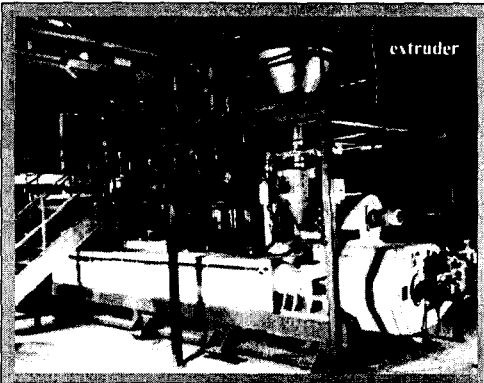
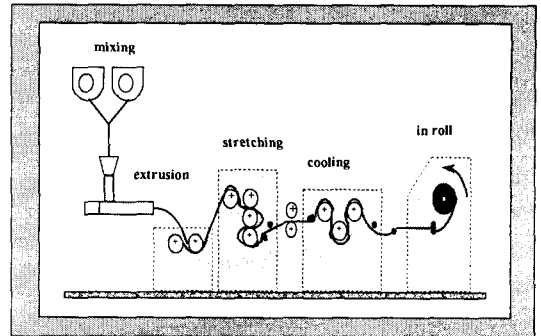
modified bituminous [BGM]

Market share in 2002

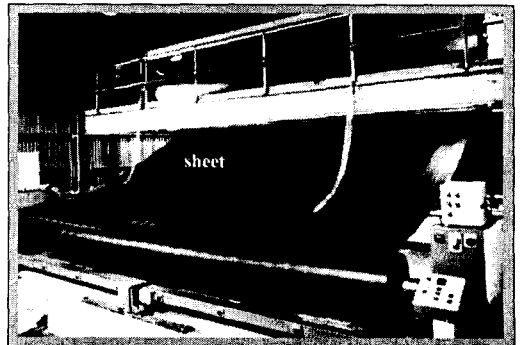
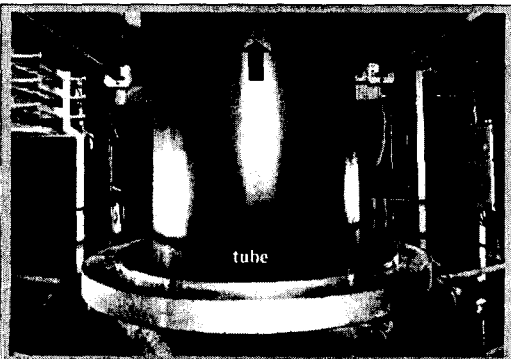
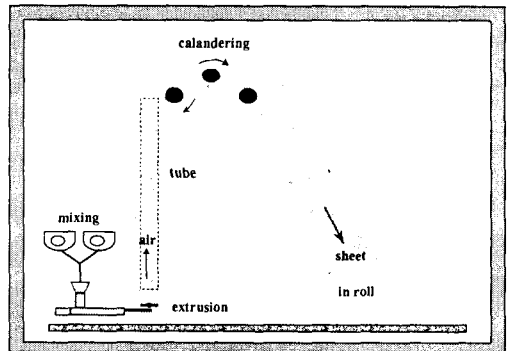


**Manufacturing
of polymeric
geomembranes**

Sheet production by slit process

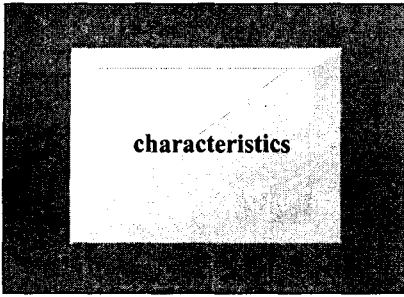


Sheet production by melt blown process



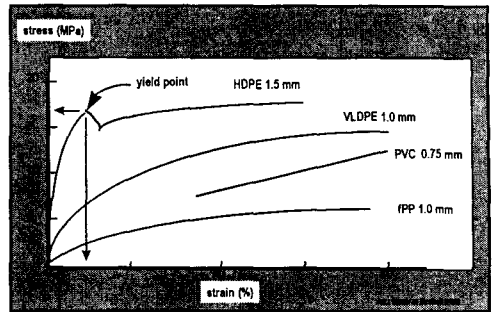
Geomembranes

characteristics



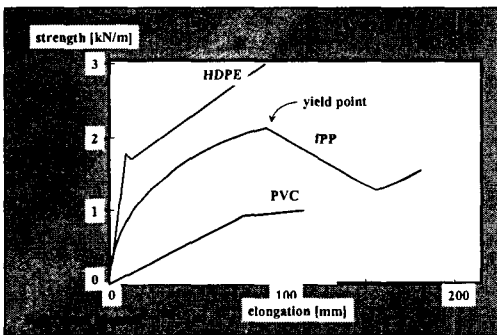
Geomembranes

Tensile resistance



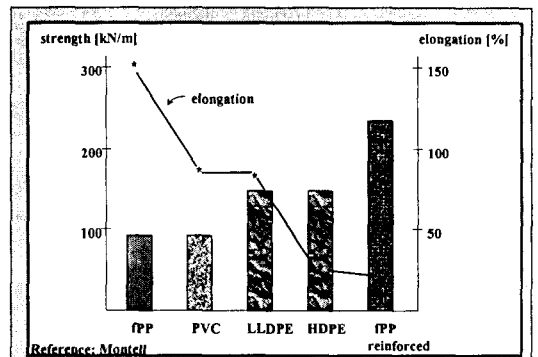
Geomembranes

Tensile resistance



Geomembranes

Strength at break



Geomembranes

Friction angle

Geomembrane	friction angle (degree)			
	Ottawa sand	river sand	geotextile	
	angle of 38 °	angle of 36 °	non woven	woven
HDPE smooth	18	18	8	11
HDPE textured		28		
LLDPE smooth		22		
PVC smooth		25	21	18
PVC texture		27	23	20
fPP reinforced	31			
fPP non reinforced	29			

reference: Montell 1998/Koerner 1998

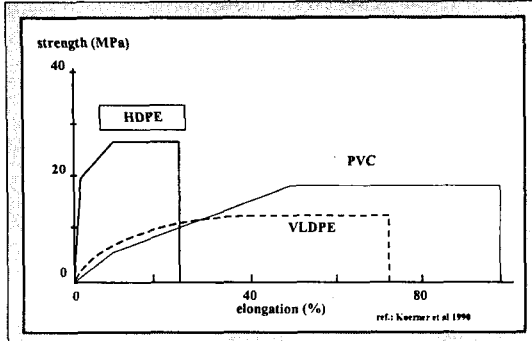
Geomembranes

Friction angle

geomembrane	friction angle at interface	material in contact	friction angle residual (degrees)
PVC	hatch surface	gbx non-woven # 1	28 to 24
	hatch surface	gbx non-woven # 2	37 to 26
	hatch surface	gbx non-woven # 3	25 to 24
	hatch surface	gbx non-woven # 4	20
	smooth surface	gbx non-woven # 4	30 to 29
HDPE	hatch surface	gbx non-woven # 5	30 to 26
	hatch surface	geodrain	34 to 23
	hatch surface	geomesh	21 to 18
	hatch surface	GCL smooth surface	21 to 10
hatch surface	GCL rough surface	21 to 18	
PVC	hatch surface	gbx non-woven # 2	37 to 26
HDPE	textured surface	gbx non-woven # 2	25 to 15
	smooth surface	gbx non-woven # 2	7 to 5
LDPE	smooth surface	gbx non-woven # 2	6 to 5
	textured surface	gbx non-woven # 2	25 to 19

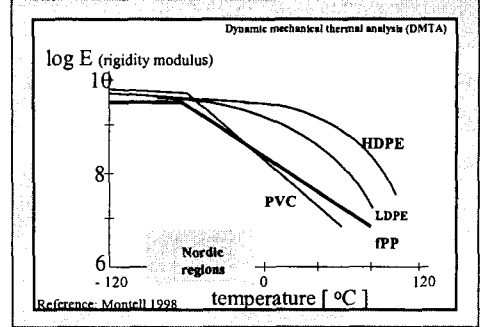
Geomembranes

Bursting resistance



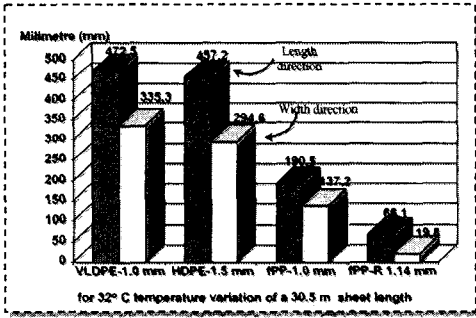
Geomembranes

flexibility



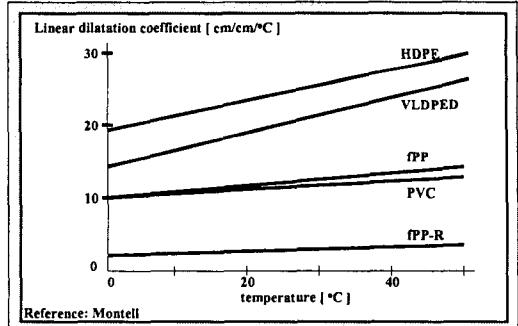
Geomembranes

Thermal elongation



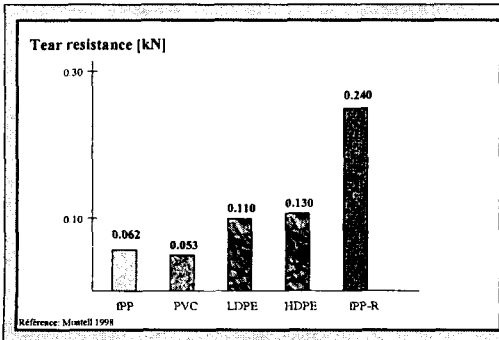
Geomembranes

Linear dilatation



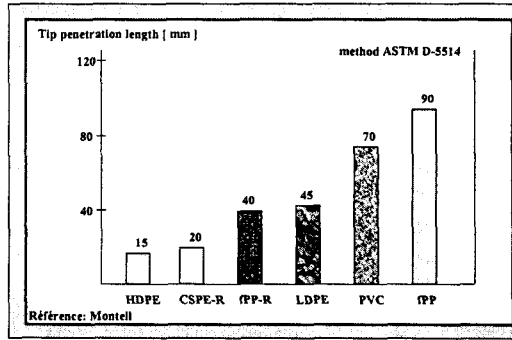
Geomembranes

Tear resistance

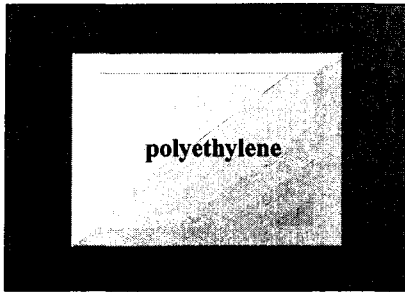


Geomembranes

Puncture resistance



Geomembranes



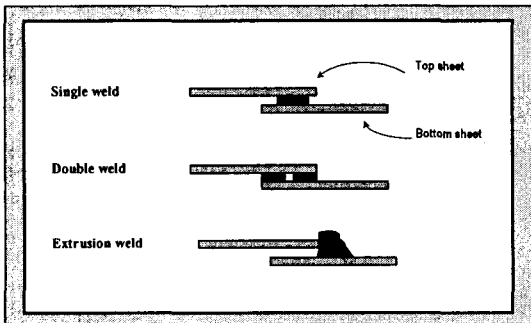
Geomembranes

Tensile resistance of HDPE GM

property	D638	D4885
maximum load (kPa)	18,600	15,900
elongation at max. load (%)	17	15
modulus (Mpa)	330	450
strength at rupture (kPa)	13,800	11,000
elongation at rupture (%)	> 500	> 400

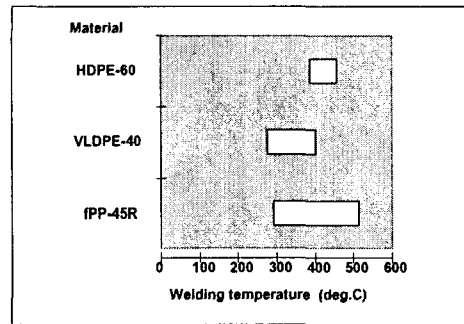
Geomembranes

Thermo fusion seams for PE geomembranes



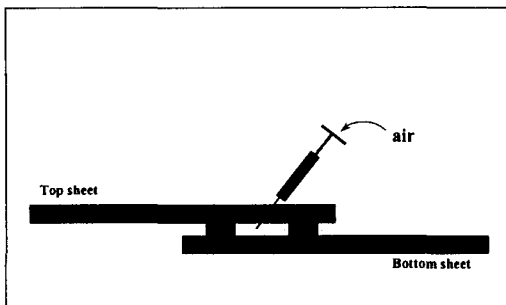
Geomembranes

Welding temperature ranges



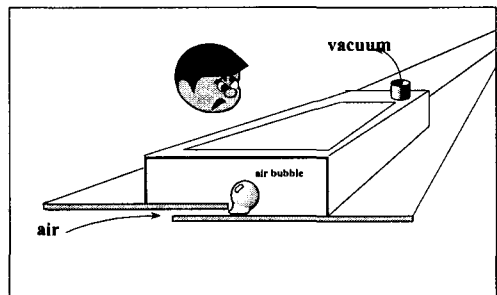
Geomembranes

Non destructive testing: double wedge seam

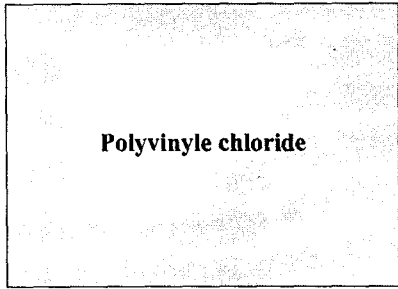


Geomembranes

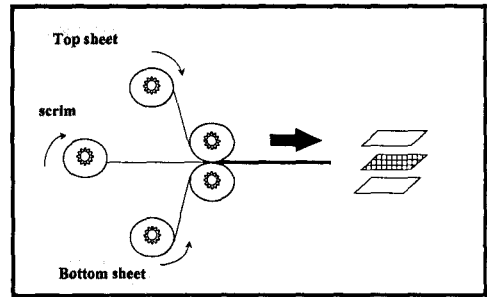
Non destructive testing: vacuum box



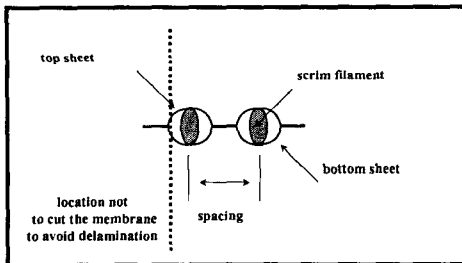
Polyvinyl chloride



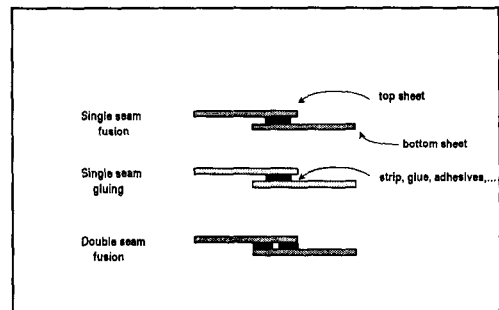
Manufacturing PVC reinforced sheet



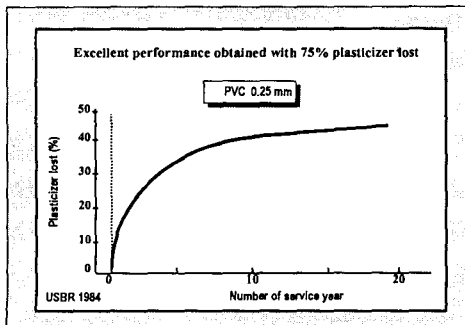
Cross section of a PVC reinforced sheet



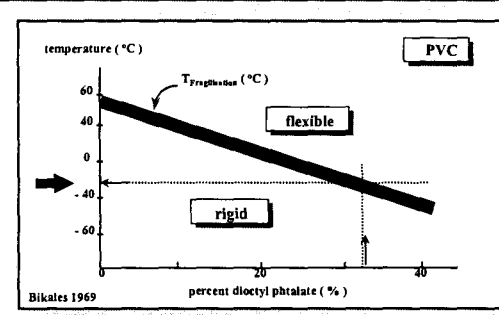
Types of seam with PVC GM



Plasticizer lost with service time in PVC geomembrane

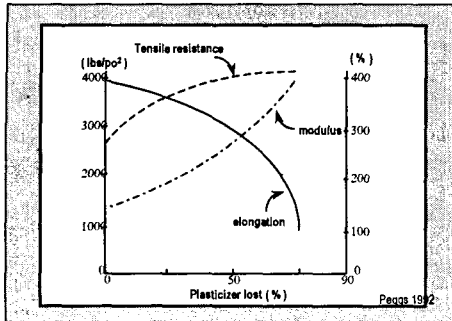


Flexibility as a function of plasticizer content



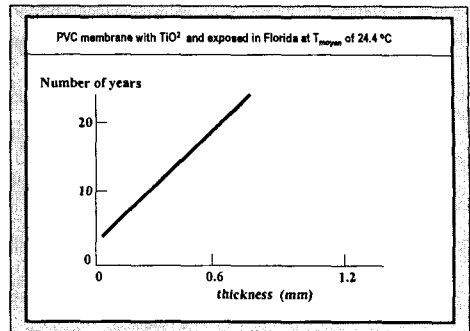
Geomembranes

Tensile resistance function of plasticizer lost in PVC geomembrane



Geomembranes

Forecasted functional life time of PVC gm



Geomembranes

flexible polypropylene

Geomembranes

fpp panels & other flexible materials

Material	covered area (m ²)	
	non-reinforced weight of 1400 kg	reinforced weight of 1800 kg
non-reinforced		
0.50 mm	2800	3700
0.75 mm	2000	2500
1.00 mm	1500	2000
reinforced		
0.50 mm	2800	3700
0.75 mm	2000	2500
0.91 mm	1750	2300
1.14 mm	1400	1900

Reference: Layfield Plastics

Geomembranes

fpp seam resistance

ASTM D-4437 modified	fpp geomembrane thickness (mm)			
	0.75	1.0	1.5	2.0
Tensile resistance (N/mm) (minimum strength 200%)	4.4	6.1	7.9	9.6
Peel resistance (N/mm) (minimum strength at Film-Tear Bond)	2.6	3.5	4.4	5.2

Reference: Montell 1996

Geomembranes

fpp chemical resistance

solution in contact for 120 days at 50 °C

product	concentration ppm	weight gain %	resistance	resistance	elongation
			creep Mpa	rupture Mpa	at rupture %
control sample			7.68	22.6	840
water			8.29	22.0	800
sodium chloride	2000	0.10	7.35	21.1	815
ketone (MEK)	1000	0.18	8.33	20.4	775
0-xylene	150	1.10	7.44	21.5	640
trichloroethylene	475	2.00	7.55	24.7	835
toluene	475	2.25	6.80	19.1	775
toluene + 2% NaCl	475	2.50	7.17	18.9	765
artificial leachate	mixture	3.70	6.66	19.2	805

Reference: Montell 1996

Geomembranes

Gas diffusion through the fPP geomembrane

ASTM D-1434	gas transmission (cc/m ² -day-atm)
methane	80 - 90
oxygen	320 - 350
carbonic dioxide	1100 - 1250

Reference: Montell 1998

Geomembranes

fPP leachate resistance

property	% of variation	
	period of 28 months	period of 40 months
resistance at rupture	-4	-2
elongation at rupture	2	-7
tensile resistance	7	-10

Reference: Montell 1998

Geomembranes

fPP micro-organisms resistance

property	property retention (%)		
	after 3 months	after a year	after 2 years
Young modulus	102	94	97
resistance at yield point at rupture	101	94	93
elongation at yield point at rupture	99	97	86

Reference: Montell 1998

Geomembranes

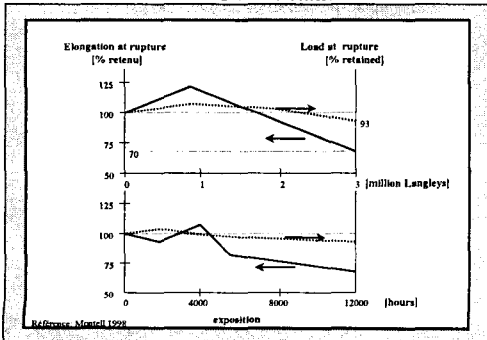
fPP soil burial resistance

property	under flotation level			over flotation level		
	3 year	4 year	6 year	3 year	4 year	6 year
resistance at rupture (kN/m)	14.8	15.1	14.2	14.7	15.4	14.8
elongation at rupture (%)	1173	1253	1233	1206	1315	1200
tensile Graves (10 ⁻³ kN/m)	63	64	65	67	66	64

Reference: Comer et al 1998

Geomembranes

fPP UV resistance

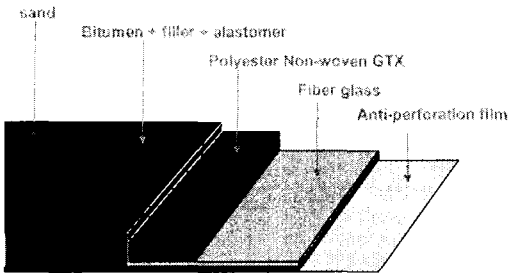


Geomembranes

bituminous

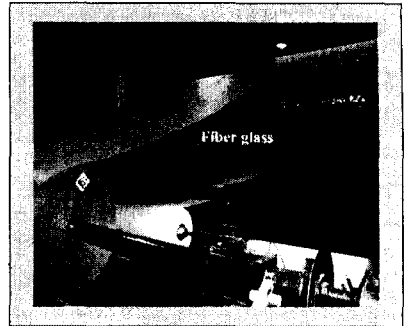
Geomembranes

BGM STRUCTURE



Geomembranes

PBGM manufacturing



Geomembranes

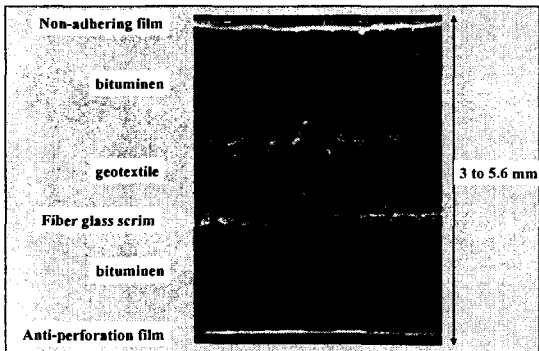


Geomembranes



Geomembranes

PBGM cross section



Geomembranes

PBGM characteristics

thickness	mm	3.3	3.9	4.8	5.6	4.0
mass/area	kg / m ²	3.7	4.5	5.5	6.5	4.8
roll length	m	100	80	65	55	80
roll width	m	5.15				
roll area	m ²	515	412	335	283	412
roll weight	kg	2000				

Geomembranes

PBGM characteristics

		AFNOR	1	2	3	4	ES	
resistance at break	KN/m	NF P84 501	14	20	25	30	23	
elongation	%	NF P84 501	> 55					
static puncture	N	NF P84 507	300	450	500	600	550	
dynamic puncture	J	NF P84 353	18	20	22	24	21	
granular puncture	KN	NF P84 510	-	15	-	> 30	-	
friction angle	°	NF EN 495-2	32 ←					
water permeability	m ³ /m ²	NF P84 515	< 10 ⁻⁴					
flexibility (cold)	‰	NF P84 350	0	0	0	0	-15	

Geomembranes

PBGM installation on top of slope



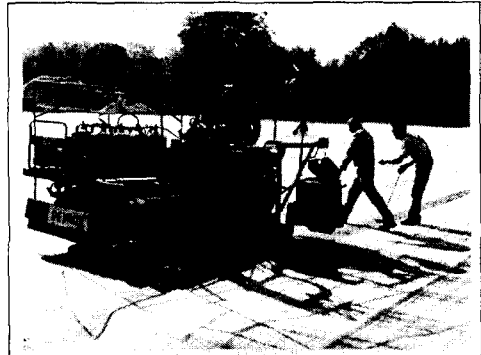
Geomembranes

Seaming manually a PFBGM with propane torch



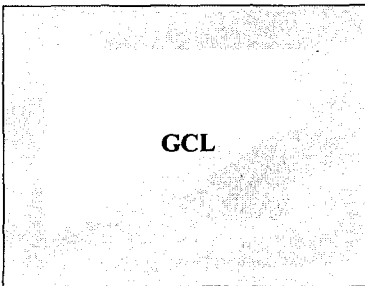
Geomembranes

Automated seaming of PBGM on flat surfaces



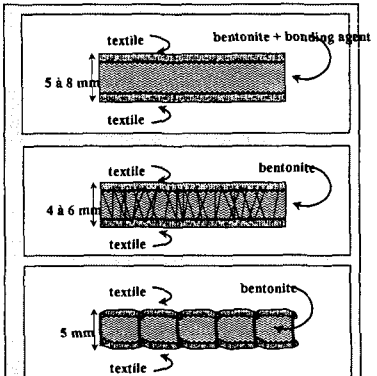
Geomembranes

GCL

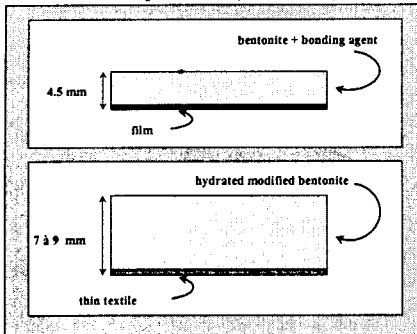


Geomembranes

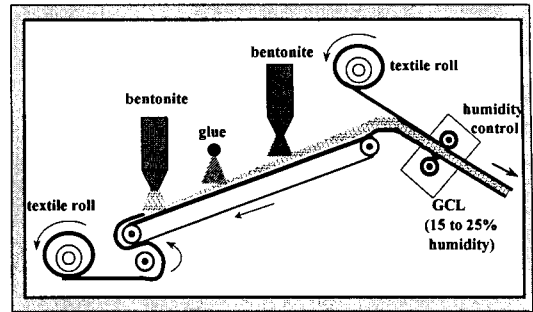
GCL Products



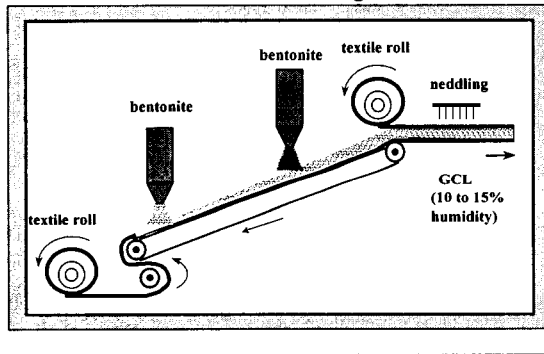
GCL products (continued)



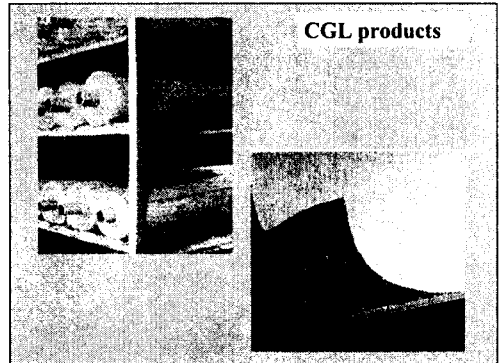
GCL manufacturing



GCL manufacturing



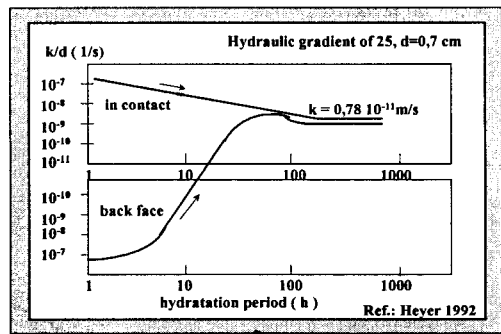
CGL products



needed				
Bentofix NS	5 kg/m ² granular Na	woven	non-woven	
Bentofix HW	5 kg/m ² powder Na	non-woven	non-woven	
Bentofix WD	3.5 kg/m ² powder Na	non-woven	non-woven	
Bentofix ES	5 kg/m ² powder Na	non-woven	non-woven	woven inter.
Bentomat ST, HD, DN	5 kg/m ² granular Na	woven 110 g/m ²	non-woven 200 g/m ²	
Bentomat HS	5 kg/m ² granular Na	woven reinforced	non-woven reinforced	
sewad				
Claymax 500SP	5 kg/m ² granular Na	woven polyester	tissé polypropylène	100 mm
NaBento	5 kg/m ² powder Ca act.	non-woven PP	non-tissé PP	20 mm
Modulo Geobent	granular Na + polymer	woven	woven	tissé inter. goujons
chemical				
Claymax 200R	granular Na + glue	woven	woven	
Gundeeal	granular Na + glue	geotext PE	aucune	scrim 20/50
hydraté Rewell	granular Ca + polymer	thin textile	aucune	
thermal				
Equiva-Seal	power + spacer	textile	textile	thermal
Triaplast	gel + sand	geotextile on site	none	?

références 64 & 65

GCL hydration time



Geomembranes

GCL permeability

Water content (%)	Permeability coef. (m/s)
17	2×10^{-5}
50	4×10^{-5}
100	1×10^{-9}
125	$< 1 \times 10^{-9}$

Geomembranes

GCL permeability

	permeability (m/s)				
	Bentofix	Bentomat	Claymax	Gundseal treated	Gundseal
dry products contact with synthetic leachate	5×10^{-7}		5×10^{-4}	8×10^{-4}	2×10^{-7}
48 h saturation contact with synthetic leachate	2×10^{-4}	1×10^{-8}	3×10^{-10}	2×10^{-7}	4×10^{-7}
produits pr? hydrat? contact with synthetic leachate				3×10^{-12}	2×10^{-11}
48 h saturation contact with real leachate	1×10^{-12}	2×10^{-10}	7×10^{-12}	6×10^{-12}	3×10^{-12}

synthetic leachate = concentration Ca of 1000 mg/l
? ? ence Ruhl et Daniel 1987

Geomembranes

GCL permeability

