Journal of Geological Resource and Engineering 4 (2015) 173-184
doi:10.17265/2328-2193/2015.04.002

Degradation of Mechanical Properties of Geotextiles and Geomembranes Exposed to Outdoor Solar Radiation under Various Exposure Conditions—Part I: Results of UV-Degradation

Dr. Vivek Ganesh Bhartu
764-E, Umrigar Building, Parsee Colony,Dadar,Mumbai,400014, India

Abstract: Geosynthetics when exposed to UV-radiation lose their mechanical properties viz. tensile strength. The degradation of strength depends upon the exposure period and more significantly the conditions under which material is exposed. Geosynthetics when used in the field are in contact with soil, water or in contact with soil and water. The degradation of strength may not be necessarily same when the material is freely exposed to UV-radiation under various exposure conditions. Experimental study has been performed on eight geotextile and eight geomembrane test specimens exposed to various exposure conditions under outdoor solar radiation. Results for degradation show that the same material has different loss of tensile strength when exposed to UV-radiation under different exposure conditions. A degradation coefficient has been introduced to evaluate actual degradation of strength for various exposure conditions. In the first part of the paper, results of degradation of tensile strength due to UV radiation are discussed and in part II results are analyzed to obtain generalized solution for assessing UV degradation for various geotextiles/geomembranes exposed under different exposure conditions.

Key words: UV-Radiation, geotextiles, geomembranes, solar radiation.

1. Introduction

It is well known that the exposure of polymers to UV-radiation can be major source of degradation of strength. This is the case for all geosynthetics comprising various polymeric materials. The degradation mechanism depends upon the intensity of the energy and the period of exposure which has been reported by several researchers. However, the previous research was based on the free exposure of material under UV-radiation. No attempt was made to assess the UV-degradation of material exposed under various exposure conditions. The degradation of strength depends upon the condition under which it is exposed to UV-radiation.

An experimental set up has been constructed at Mumbai for assessing degradation of strength due to outdoor solar radiation. Eight geotextile specimens of PET/PP and eight geomembrane test specimens of PVC/HDPE are exposed to outdoor solar radiation under exposure condition;

(1) freely exposed to UV-radiation;

(2) submerged in water and exposed to UV-radiation;

(3) in contact with soil and exposed to UV- radiation;

(4) in contact with soil and water and exposed to UV-radiation.

The results for degradation of strength are discussed below. From the present study a degradation coefficient has been arrived to evaluate the degradation of strength of geotextiles/geomembranes exposed to outdoor solar radiation under various exposure conditions.

Corresponding author: Vivek Ganesh Bhartu, Ph.D., consulting engineer, research field: geo-technical engineering.

2. Significance of Present Study

Geosynthetics are widely used in geotechnical applications like soil slope stabilization, silt fences, earthen canal liners, side embankment of paved/unpaved roads, soil retaining walls etc.

The manufactures provide the guarantee of material for the retained strength against UV-radiation exposure. However, the procedure of assessing the strength loss is to expose the material freely for certain hours (500 hrs) under artificial UV-radiation. This guarantee of retained strength may not hold good when the material is used in actual field. There are several other factors which affect the amount of degradation when the material is exposed to UV-radiation under various conditions. The actual degradation of strength is significant to be considered for selection of proper and suitable material and to predict the life of the material in actual field.

Geosynthetics when used in geotechnical applications, the combination of exposure conditions along with exposure to UV-radiation are:

(1) freely exposed to UV-radiation as used in water/oil storage tanks;

(2) submerged in water and exposed to UV-radiation as used in silt fences, primary earthen canal liners etc.;

(3) in contact with soil and exposed to UV-radiation as used in soil retaining walls, side embankment of paved/unpaved roads, soil slope stabilisers etc.;

(4) in contact with soil and water and exposed to UV-radiation as used in earthen canal liners, dam liners etc.

The geotextile/geomembrane test specimens are exposed to outdoor solar radiation under the above exposure conditions to determine the actual degradation of strength thus enabling to predict the life of material.

3. Literature Review

Observations reported by earlier researchers have been studied.

Calhoun [1] reported that the geotextile fabrics are adversely affected by UV-radiation. These observations were derived from solar experiments performed on woven and nonwoven geotextiles. This conclusion was confirmed by a number of subsequent researchers.

Raumann [2] suggested that UV-degradation is based upon the expected sunhours, energy of sunlight impining on geotextiles and other factors such as temperature, humidity and atmosphere pollution.

Van Wijk and Stoerzer [3] reported that the effect of natural weathering depends upon geographical latitude as shown in Fig. 1 which shows annual irradiated energy in KLy (one KiloLangley is equivalent to 1 Kcal/m^2 or 41.8 MJ/m^2 irradiated energy).

Greenway et al. [4] reported the results on six nonwoven geotextiles in Hongkong. The test specimens were polyester, polypropylene, Polypropylene-polyethylene. All the test specimens lost some strength.

Rankilor [5] assessed empirically the relative degradation rates of wide range of geotextiles in different environments and reported that geotextiles exposed in Sweden and England lost 14% to 22% their original strength.

Brand and Pang [6] performed experimental study on twelve nonwoven, one woven and one composite geotextile and observed that all geotextiles lost strength and became more brittle after exposure to direct sunlight and weather.

Koerner et al. [7] reported that Geotextiles lost their tensile strength when exposed to outdoor solar radiation and also reported that the degradation magnitude is different for the place where direct normal solar radiation is different.

They have also suggested that the synergistic effect of UV-degradation rates and elevated temperature depends upon the moisture content, environmental effect and site-specific phenomena. Water itself may not be destructive, but it can bring oxygen into direct contact with the polymer thereby promoting the oxidation and moisture is considered to be a lubricant allowing for more UV-degradation. The method of water

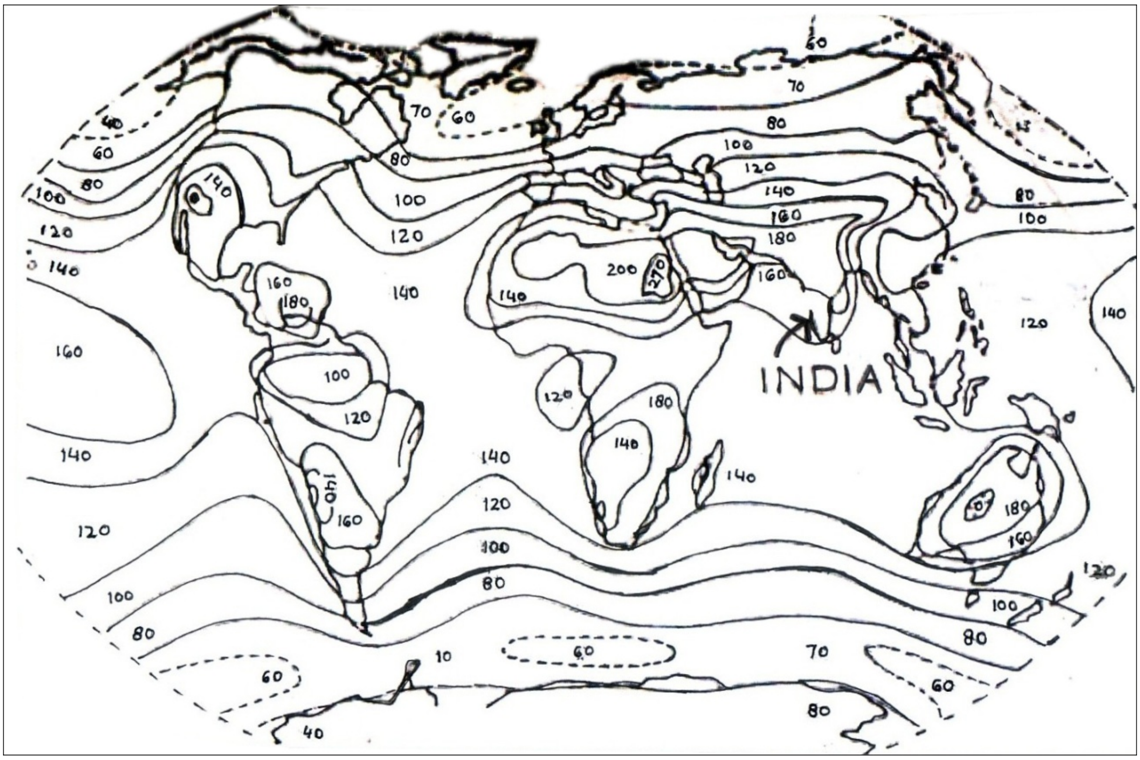


Fig. 1 Generalized isolines of annual global radiation in KLy (kcal/cm) [after M.G. Landsberg (Van Wijk and Stoerzer 198 E)].

application can vary the degradation magnitude viz. constant submergence, partial submergence, high humidity, fog, spray and condensation have different effect.

Hsuan et al. [8] observed that notched constant tensile load test results on seven years old exposure geomembranes show the densification effect and the density of geomembranes gradually increases with time due to recrystallization. This probably decreases the tensile strength and stress cracking resistance of geomembranes.

Hirt and Searle [9] suggested that the degradation mechanism depends upon the activation spectra on polymers which are constituents of geosynthetic material. It is also suggested that the activation spectra for PE, PP, PVC and PET are 300 nm, 370 nm, 320 nm and 325 nm respectively below which polymer loses its tensile strength due to bond breakage.

Koerner [10] reported that UV region is most sensitive portion of spectrum which causes degradation. However, visible light and infrared portion of light serve as heat sources that lead to synergistic effect. Koerner also reported that geographical location, temperature, cloud cover, wind and moisture are important factors in the UV degradation process.

From the reports of earlier researchers, it has been observed that the degradation of strength depends upon the condition under which geotextiles/geomembranes are exposed to UV-radiation.

4. Experimental Set-up for Outdoor Exposure under Solar Radiation

An experimental set up was constructed on the open terrace slab of Sardar Patel College of Engineering (Mumbai). Test specimens were placed facing North-South direction by making the angle of 45^0 to the ground surface in order to absorb optimum incidental solar radiation by test specimens.

Details of experimental set up are shown in Fig. 2.

Four test samples of polyester, polypropylene, polyvinylchloride and high density polyethylene were selected and placed by making an angle of 45^0 to the

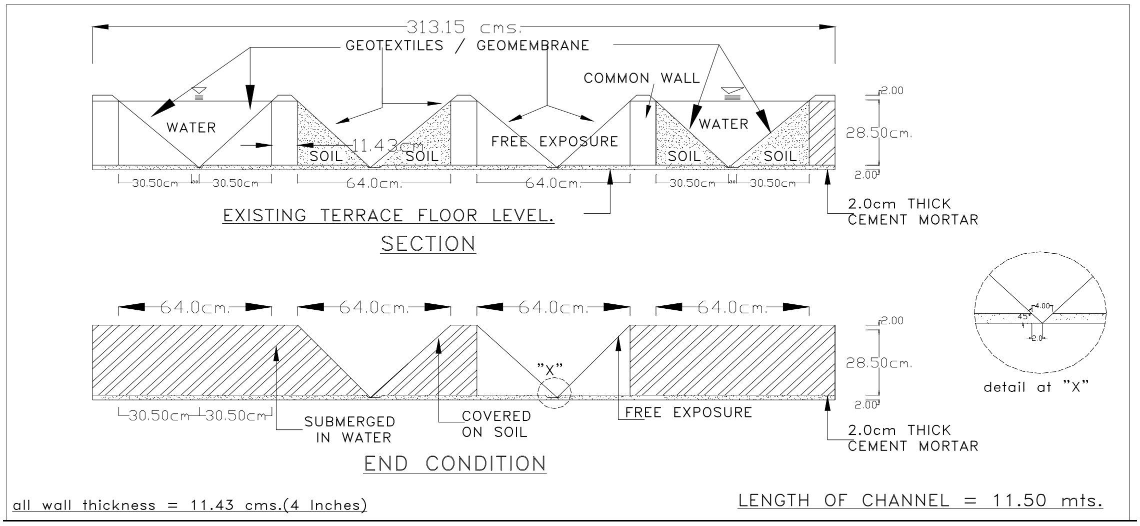


Fig. 2 Experimental set-up for outdoor solar exposure of geomembranes/geotextiles.

Table 1 List of test specimens of geotextiles and geomembranes.

Sr. No.	Polymer material	Notation	Mass per unit area (gm/m^2)	Thickness (mm)	Original tensile strength (MPa)
1	Polyester-Nonwoven, Needle punched + saturated	PET-1	100	1.2	3.21
2	Polyester-Nonwoven Needle punched + saturated	PET-2	280	2.1	3.41
3	Polyester-Nonwoven Needle punched + saturated	PET-3	550	4.0	4.12
4	Polyester woven multifilament	PET-4	12	0.2	2.41
5	Polypropylene-Nonwoven, saturated	PP-1	75	1.2	4.95
6	Polypropylene-Nonwoven Needle punched	PP-2	150	1.2	5.65
7	Polypropylene-Nonwoven Needle punched	PP-3	225	1.6	6.23
8	Polypropylene- woven Needle punched	PP-4	300	1.05	5.12
9	Polyvinyl Chloride UV-unstabilized	PVC-1	517.03	0.5	15.23
10	Polyvinyl Chloride UV-unstabilized	PVC-2	978.5	1.0	19.85
11	Polyvinyl Chloride UV-unstabilized	PVC-3	1550	1.7	22.24
12	Polyvinyl Chloride UV-stabilized	PVC-4	550	0.5	15.27
13	High Density Polyethylene UV-stabilized	HDPE-1	450	0.5	22.15
14	High Density Polyethylene UV-stabilized	HDPE-2	601	0.7	25.1
15	High Density Polyethylene UV-stabilized	HDPE-3	1,450	1.5	28.53
16	High Density Polyethylene UV-unstabilized	HDPE-4	1,374	1.5	22.10

ground surface as shown in Fig. 2.

The list of geotextile/geomembrane test specimens is shown in Table 1.

The duration of the exposure of test specimens under outdoor solar radiation has been selected as 1 month, 3 months, 6 months and 12 months, i.e., one year cycle comprising all seasons.

The degradation of tensile strength of geotextile/geomembrane test specimens has been measured by following standard test methods:

(1) Tensile strength of geotextile test specimens (PET/PP) has been tested by ASTM–D 4595;

(2) Tensile strength of PVC has been tested by ASTM–D 882;

(3) Tensile strength of HDPE has been tested by ASTM–D 638.

5. Results on Degradation of Mechanical Properties

The degradation of mechanical properties viz, loss of tensile strength has been presented in Table 2.

The variation of retained strength (in %) of geotextile

Table 2 Results showing the loss of tensile strength of geotextile/geomembrane test specimens exposed to outdoor UV-radiation for various conditions.

Sr. No.	Geotextile Code No.	Exposure period in months	Conditions			
			Freely exposed	Submerged in water	In contact with soil	In contact with soil and water
			Retained strength in %	Retained strength in %	Retained strength in %	Retained strength in %
1	PET-1	Unexposed	100	100	100	100
	1.2 mm thick	1	92	97	85	79
	100 gm/m^2	3	76	81	69	63
	Nonwoven	6	56	61	49	43
		12	31	35	26	20
2	PET-2	Unexposed	100	100	100	100
	2.1 mm thick	1	96	97	98	92
	280 gm/m^2	3	92	97	85	79
	Nonwoven	6	72	77	65	59
		12	43	49	36	30
3	PET-3	Unexposed	100	100	100	100
	4 mm thick	1	98	100	99	95
	550 gm/m^2	3	98	99	91	85
	Nonwoven	6	80	85	73	67
		12	50	55	43	37
4	PET-4	Unexposed	100	100	100	100
	0.2 mm thick	1	90	95	83	76
	12 gm/m^2	3	72	77	65	59
	Woven	6	51	56	44	38
		12	30	36	25	20
5	PP-1	Unexposed	100	100	100	100
	1.2 mm thick	1	88	93	81	75
	75 gm/m^2	3	74	79	67	61
	Nonwoven	6	54	59	47	41
		12	29	34	22	16
6	PP-2	Unexposed	100	100	100	100
	1.2 mm thick	1	91	96	83	78
	150 gm/m^2	3	75	80	68	62
	Nonwoven	6	61	66	54	48
		12	37	43	30	24
7	PP-3	Unexposed	100	100	100	100
	1.6 mm thick	1	92	97	85	79
	225 gm/m^2	3	78	82	71	65
	Nonwoven	6	65	70	58	52
		12	40	46	33	27
8	PP-4	Unexposed	100	100	100	100
	1.05 mm thick	1	93	98	86	80
	300 gm/m^2	3	82	87	75	69
	Woven	6	69	74	62	56
		12	47	52	40	34

(Table 2 continued)

Sr. No.	Geotextile Code No.	Exposure period in months	Conditions			
			Freely exposed	Submerged in water	In contact with soil	In contact with soil and water
			Retained strength in %	Retained strength in %	Retained strength in %	Retained strength in %
9	PVC-1	Unexposed	100	100	100	100
	0.5 mm thick	1	95	99	88	83
	517 gm/m^2	3	86	92	79	74
	UV-unstabilized	6	75	81	68	63
		12	47	53	40	35
10	PVC-2	Unexposed	100	100	100	100
	1 mm thick	1	95	99	89	84
	978 gm/m^2	3	88	94	82	77
	UV-unstabilized	6	78	84	72	67
		12	49	55	43	38
11	PVC-3	Unexposed	100	100	100	100
	1.70 mm thick	1	96	99	90	85
	1,550 gm/m^2	3	89	95	83	78
	UV-unstabilized	6	79	85	73	68
		12	51	57	45	39
12	PVC-4	Unexposed	100	100	100	100
	0.5 mm thick	1	96	99	90	85
	550 gm/m^2	3	88	94	82	77
	UV-stabilized	6	77	83	71	66
		12	50	56	44	38
13	HDPE-1	Unexposed	100	100	100	100
	0.5 mm thick	1	94	99	88	83
	450 gm/m^2	3	87	94	81	76
	UV-stabilized	6	80	87	74	69
		12	54	61	48	42
14	HDPE-2	Unexposed	100	100	100	100
	0.70 mm thick	1	95	99	90	85
	601 gm/m^2	3	88	95	83	78
	UV-stabilized	6	82	89	77	72
		12	56	63	51	46
15	HDPE-3	Unexposed	100	100	100	100
	1.50 mm thick	1	96	99	91	86
	1,450 gm/m^2	3	90	97	85	80
	UV-stabilized	6	85	92	80	75
		12	59	66	53	48
16	HDPE-4	Unexposed	100	100	100	100
	1.5 mm thick	1	96	99	90	85
	1,374 gm/m^2	3	88	94	82	78
	UV-unstabilized	6	83	89	77	72
		12	57	63	51	46

1 month = 150 Kw.h/m^2 solar radiation
3 months = 450 Kw.h/m^2 solar radiation
UV content = 6.8%
6 months = 900 Kw.h/m^2 solar radiation
12 months = 1800 Kw.h/m^2 solar radiation
Station = Mumbai

test specimens with respect to exposure period (in hours) has been shown in Figs. 3-6 for various exposure conditions.

The variation of retained strength (in %) of geomembrane test specimens with respect to exposure period (in hours) has been shown in Figs. 7-10 for various exposure conditions.

6. Discussion on Degradation of Mechanical Properties

From Table 2, it is seen that all the geotextiles lost their tensile strength from 50% to 70% when freely exposed to outdoor solar radiation for 12 months (1,800 Kw.h/m^2). Geomembranes lost their tensile strength from 40% to 53% when freely exposed to outdoor solar radiation for 12 months.

The loss of tensile strength of geotextiles/geomembranes is 6% to 8% less when submerged in water and exposed to outdoor solar radiation as compared to freely exposed to outdoor solar radiation.

The loss of tensile strength of geotextiles/geomembranes is 6% to 8% more when in contact with soil and exposed to outdoor solar radiation as compared to freely exposed to outdoor solar radiation.

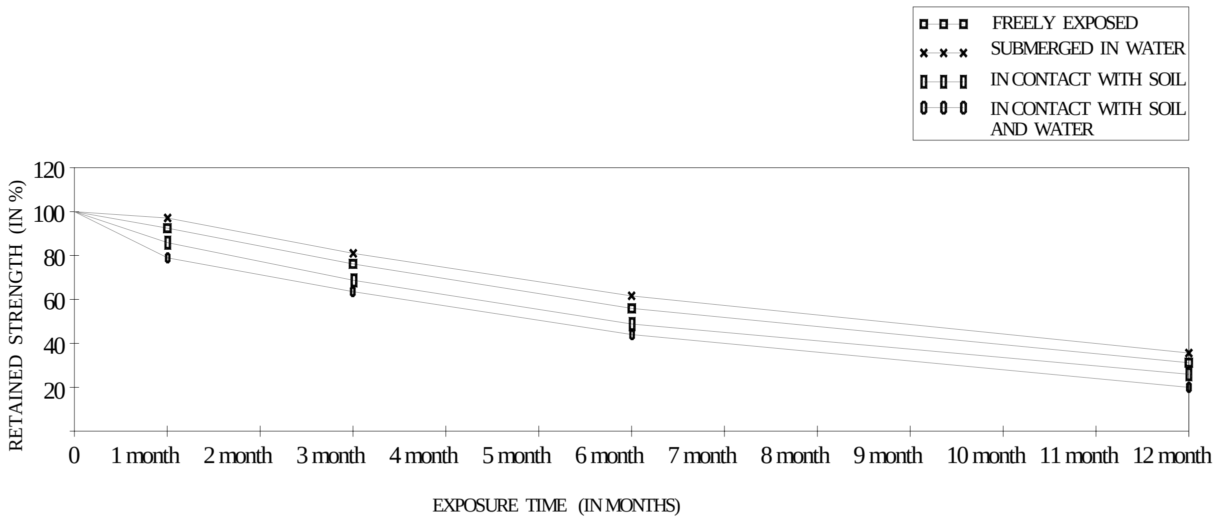


Fig. 3 Variation of retained strength of PET-1 (nonwoven) exposed to outdoor solar radiation for various conditions.

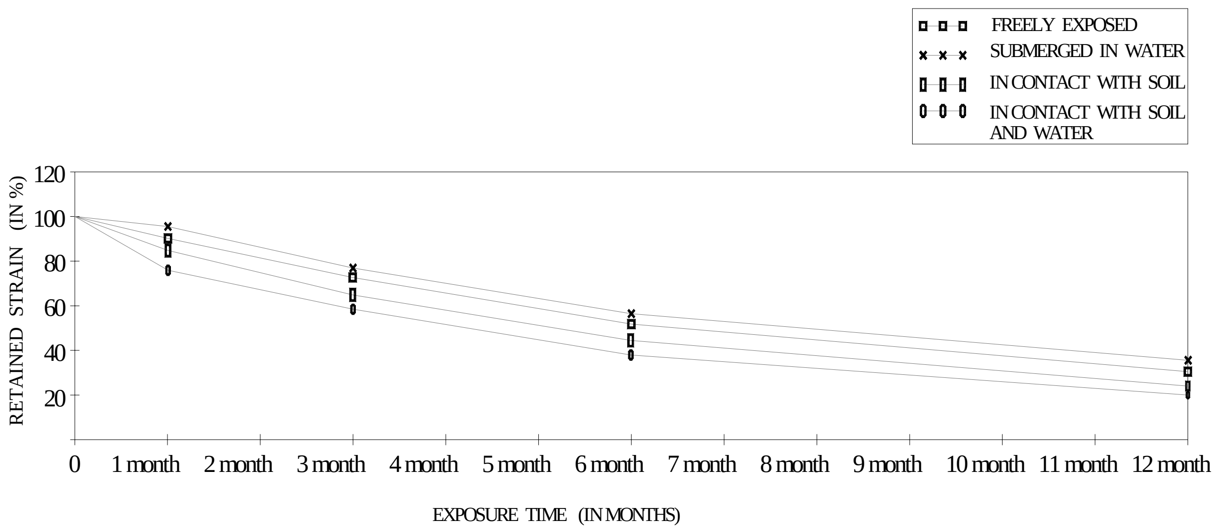


Fig. 4 Variation of retained strength of PET-4 (woven) exposed to outdoor solar radiation for various conditions.

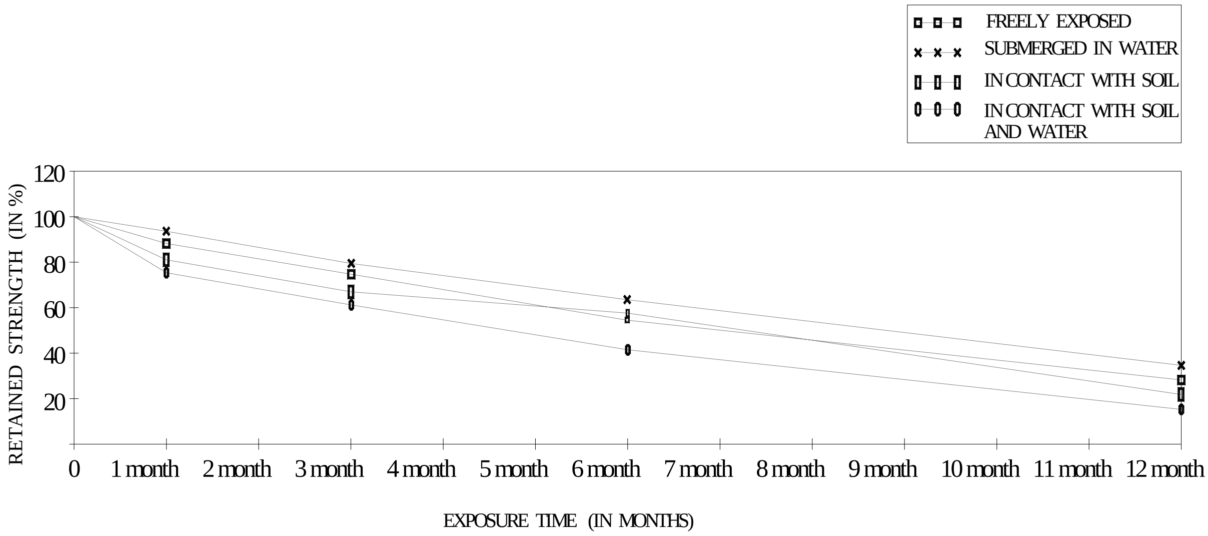


Fig. 5 Variation of retained strength of PP-1 (nonwoven) exposed to outdoor solar radiation for various conditions.

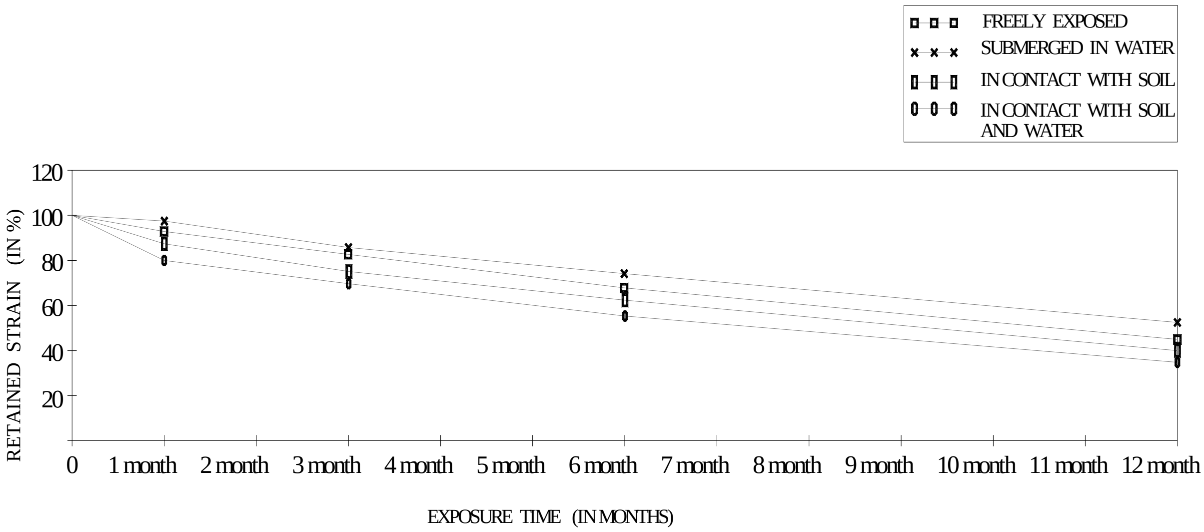


Fig. 6 Variation of retained strength of PP-4 (woven) exposed to outdoor solar radiation for various conditions.

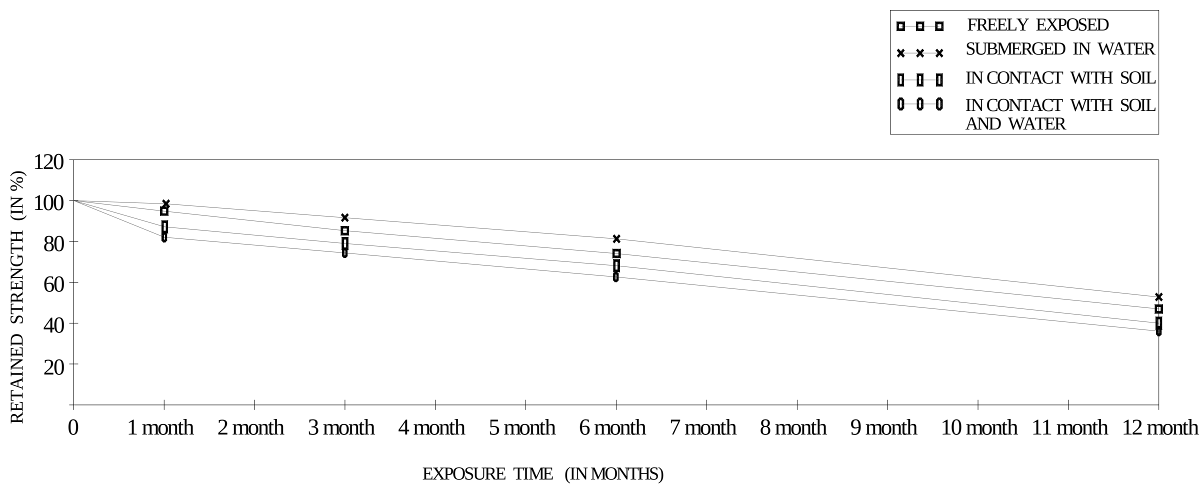


Fig. 7 Variation of retained strength of PVC-1 (UV-unstabilized) exposed to outdoor solar radiation for different conditions.

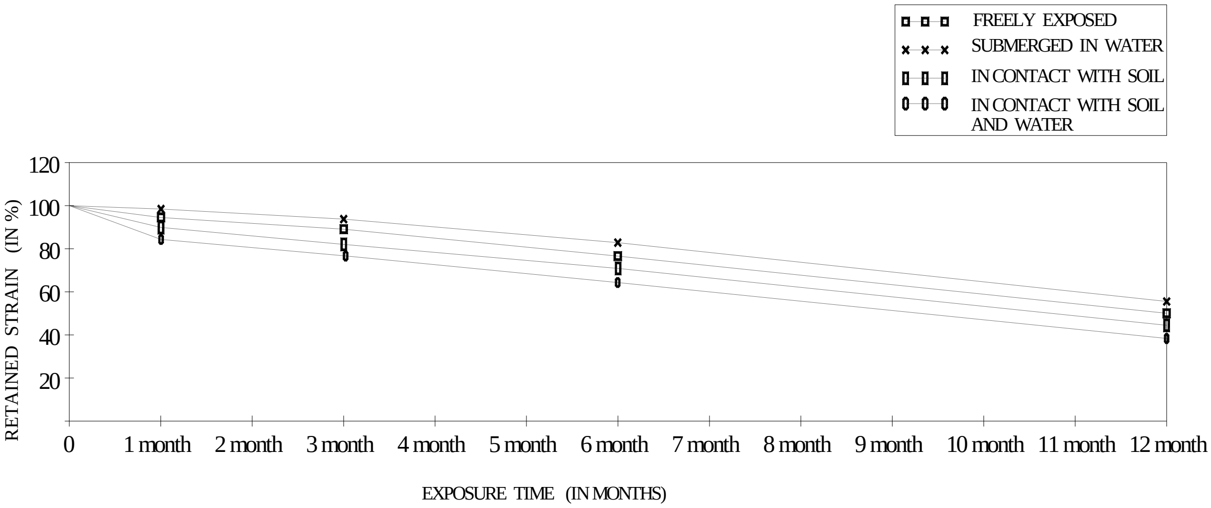


Fig. 8 Variation of retained strength of PVC-4 (UV-stabilized) exposed to outdoor solar radiation for different conditions.

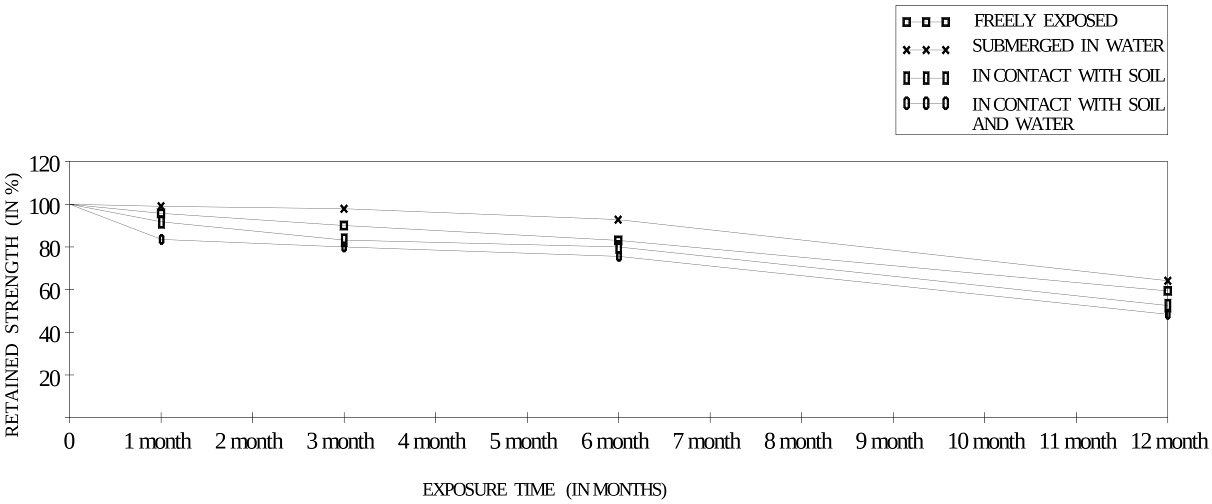


Fig. 9 Variation of retained strength of HDPE-3 (UV-stabilized) to outdoor solar radiation for different conditions.

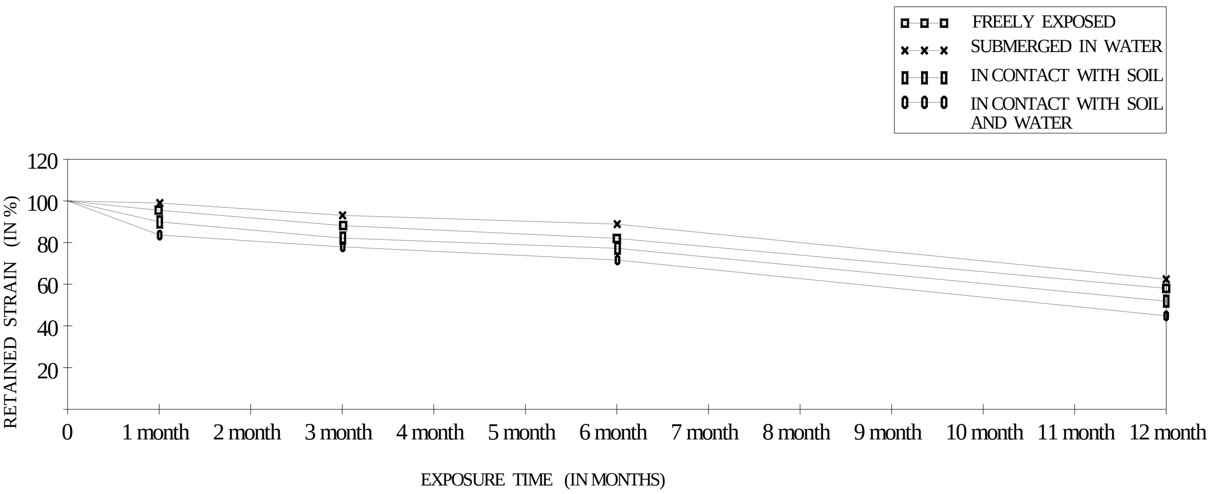


Fig. 10 Variation of retained strength of HDPE-4 (UV-unstabilized) to outdoor solar radiation for different conditions.

Table 3 Results showing degradation coefficient for retained tensile strength of geotextile/geomembrane test specimens exposed to outdoor solar radiation for various conditions.

Sr. No.	Geotextile/geomembrane Code No.	Exposure period in months	Conditions			
			Freely exposed	Submerged in water	In contact with soil	In contact with soil and water
			Degradation coefficient	Degradation coefficient	Degradation coefficient	Degradation coefficient
1	PET-1	12	1.000	1.129	0.839	0.645
2	PET-2	12	1.000	1.139	0.837	0.698
3	PET-3	12	1.000	1.100	0.860	0.740
4	PET-4	12	1.000	1.200	0.833	0.667
5	PP-1	12	1.000	1.172	0.759	0.552
6	PP-2	12	1.000	1.162	0.811	0.648
7	PP-3	12	1.000	1.150	0.825	0.675
8	PP-4	12	1.000	1.106	0.851	0.723
9	PVC-1	12	1.000	1.128	0.851	0.745
10	PVC-2	12	1.000	1.122	0.878	0.776
11	PVC-3	12	1.000	1.118	0.882	0.765
12	PVC-4	12	1.000	1.120	0.880	0.760
13	HDPE-1	12	1.000	1.130	0.889	0.778
14	HDPE-2	12	1.000	1.125	0.911	0.821
15	HDPE-3	12	1.000	1.119	0.898	0.814
16	HDPE-4	12	1.000	1.105	0.895	0.807

12 months = 1,800 Kw.h/m^2 solar radiation.

The loss of tensile strength of geotextiles/geomembranes is 12% to 14% more when in contact with soil and water and exposed to outdoor solar radiation as compared to freely exposed to outdoor solar radiation.

As geotextiles, polyester performs better as compared to polypropylene for all exposure conditions and as geomembranes, HDPE performs better as compared to PVC for all exposure conditions.

Additions of UV-stabilizers in geotextiles/geomembranes reduce the loss of strength. However, for long duration of exposure, the UV-stabilizer once consumed, the rate of degradation becomes almost same.

The UV-degradation is function of exposure period and mass per unit area of geotextiles/geomembranes. The longer the exposure period, the higher the degradation of strength and the higher the mass per unit area of material, the lesser the degradation of strength.

7. Degradation Coefficient

From Table 2, it has been observed that the degradation of strength due to exposure to UV-radiation is not same for various exposure conditions. Hence degradation coefficient has been introduced as follows:

Degradation coefficient for intended use	=	% retained strength for intended use
		% retained strength for free exposure

The percentage retained tensile strength for various exposure conditions can be obtained by multiplying the (%) retained tensile strength for free exposure by degradation coefficient. The factor of safety for UV-degradation of geotextile/geomembrane has to be modified accordingly.

The degradation coefficient for various materials for different condition is presented in Table 3.

8. Conclusions

The loss of tensile strength of geotextiles/geomembranes is 6% to 7% less when submerged in water as compared to freely exposed to outdoor solar radiation. This may be due to water layer above test specimens which prevents penetration of

UV-photons on the material.

The loss of tensile strength of geotextiles/geomembranes is 6% to 8% more when in contact with soil as compared to freely exposed to outdoor solar radiation. This may be due to presence of salt, chemicals and metals present in the saturated soil.

The loss of tensile strength of geotextiles/geomembranes is 12% to 14% more when contact with soil and water as compared to freely exposed to outdoor solar radiation. This may be due to chemicals, metals and salt present in the soil and water.

The woven geotextiles perform better as compared to nonwoven geotextiles for all exposure conditions due to its fabric weaving pattern.

UV-degradation can be reduced by adding UV-stabilizers in geotextiles/geomembranes. However, for long duration the degradation becomes almost same due to consumption of UV-stabilizers for long duration.

The loss of tensile strength is function of exposure period and mass per unit area of geotextiles/geomembranes. The UV-degradation is function of exposure period and mass per unit area of geotextiles/geomembranes. The longer the exposure period, the higher the degradation of strength and the higher the mass per unit area of material, the lesser the degradation of strength.

The results are analyzed by two different approaches and are presented in part II to assess UV degradation of various geotextiles/geomembranes.

References

[1] Calhoun Jr, C. C. 1972. *Development of Design Criteria and Acceptance Specifications for Plastic Filter Cloths.* Technical Report No. S-72-7, U.S. Army Waterways Experiment Station, Vicksburg, Miss.

[2] Raumann, G. 1982. "Outdoor Exposure Tests of Geotextiles." *Proc. 2nd Int. Conf. on Geotextiles*, 541-6.

[3] Van Wijk, W., and Stoerzer, M. 1986. "UV Stability of Polypropylene." *Proc. 3rd Int. Conf. on Geotextiles*, 851-5.

[4] Greenway et al. 1986. "Filtration and Degradation Behavior of Some Nonwoven Geotextiles in Hong Kong." *Proc. 3rd Inst. on Geotextiles*, 605-9.

[5] Rankilor, P. R. 1988. "Problems Relating to Light Degradation and Site Testing Geotextiles—Interim Results of an International Weathering Programme." Durability of Geotextiles, Chapman and Hall, London, England, 197-206.

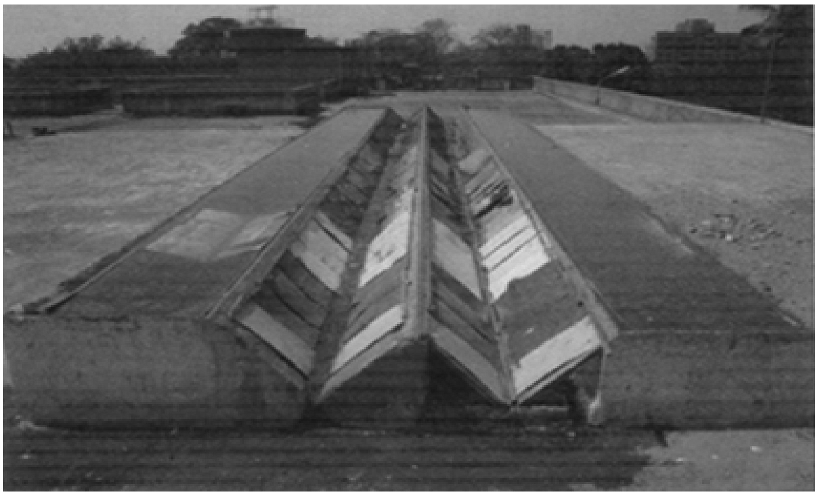
[6] Brand, E. W., and Pang, R. P. L. 1991. "Durability of Geotextile to Outdoor Exposure in Hong Kong." *Journal of Geotechnical Engineering* 117 (7): 979-1,000.

[7] Koerner, G. R., Hsuan, G. Y., and Koerner, R. R. 1998. "Photo-Initiated Degradation of Geotextile". *Journal of Geotechnical and Geoenvironmental Engineering* 124 (12): 1159-66.

[8] Hsuan et al. 1991. "Effect of Outdoor Exposure on a High Density Polyethylene Geomembrane." *Geosynthetics conf. on Industrial Fabric Association Inc. St. Paul Minn*., 287-302.

[9] Hirt, R. C., and Searle, N. D. 1972. "Energy Characteristics of Outdoor and Indoor Exposure Sources and Their Relation to the Weatherability of Plastics." American Cyanamid Corp., Parsippany, N. J. 218.

[10] Koerner, G. R. 1998. "Photo-Initiated Degradation of Geo-textiles." *Journal of Geotechnical and Geo-environmental Engineering*.



Test specimens exposed to outdoor solar radiation.