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General Solution to Evaluate Degradation of Strength of Geotextiles and Geomembranes Exposed to Solar Radiation under Various Conditions—Part II: Analysis of Results of UV-Degradation

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Abstract: Geotextiles and geomembranes lose their tensile strength when exposed to solar radiation. The loss of strength depends upon the intensity of radiation, exposure period, mass per unit area of the material. The loss of strength further depends upon the condition under which material is exposed to solar radiation. To assess the extent of degradation, eight test specimens of geotextiles and eight test specimens of geomembranes were exposed to solar radiation under various conditions at Mumbai for one year cycle comprising all seasons. The results of UV degradation of strength are presented in part I. The experimental results of degradation are analyzed with two different approaches and general solution for degradation of strength has been established for life prediction of geotextiles/geomembranes in field. The analyses of results are presented in this part II.

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

1. Introduction and Significance

It is well established that polymeric materials used as geotextiles/geomembranes lost their mechanical properties when exposed to solar radiation. The loss of strength of material is a function of solar radiation intensity, mass per unit area of material and the total incidental solar energy (exposure period). These polymeric materials when used in engineering applications are exposed under different conditions viz. freely exposed, submerged in water, in contact with soil and in contact with soil and water.

To examine the degradation of strength experimentally, four test specimens of PET and PP each, widely used as geotextiles and four test specimens of PVC and HDPE each, widely used as geomembranes were exposed to solar radiation at Mumbai having daily average solar intensity of 5,000 w.h./m²/day for different exposure conditions. The exposed specimens were tested in laboratory and the degradation of the strength has been assessed.

Previous researchers have carried out experimental study on UV-degradation of geotextiles/geomembranes by freely exposing the material under artificial UV-radiation and outdoor solar radiation in the areas like Hongkong, Texas, Philadelphia, Spartenburg etc. and quantified the degradation of strength due to exposure in UV-radiation. No attempts have been made to analyze the results to establish general solution to evaluate UV-degradation of geotextiles/geomembranes under different exposure conditions.

The experimentally observed results of present study of UV-degradation are analyzed with two different approaches and general solution for UV-degradation has been established. Both the approaches are presented here.

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2. Experimental Results of Degradation of Tensile Strength

The test specimens of geotextiles/geomembranes were exposed to solar radiation at Mumbai where solar radiation intensity is 5,000 w.h./m^2/day for one year. In order to facilitate the analysis, the degradation of test specimens has been observed after 1 month, 3 months, 6 months and 12 months, i.e., one full year cycle comprising all seasons in Mumbai.

The experimentally observed results are presented in Table 1.

3. First Approach for Analysis of Results

The first approach is graphical solution to evaluate UV-degradation of geotextiles/geomembranes exposed under various exposure conditions.

From Table 1, it has been observed that loss of tensile strength of geotextiles/geomembranes is function of mass per unit area of material and the exposure period.

Earlier researchers have reported that the economical range of mass per unit area of geotextiles is from 135 gm/m^2 to 685 gm/m^2. In the present study, three test specimens between the range, from 100 gm/m^2 to 550 gm/m^2 were used which is nearer to economical range.

Graphs for variation of retained tensile strength (in %) against mass per unit area (gm/m^2) are drawn for 3 months, 6 months and 12 months. The graphs are shown in Figs. 1-3.

By using software "OriginPro 7.5" the data have been plotted which yields an exponential curve. The equation of curve has been obtained which is equation for UV-degradation for various exposure periods.

The equations for UV-degradation are exponential curves in the form of:

$$Y = A\, e^{\rho/B} + C$$

where,

Y = retained tensile strength of the material;

ρ = mass per unit area of the material;

A, B, C are coefficients of UV-degradation equations.

The values of coefficients A, B and C are presented in Table 2.

By using the equations for degradation, the loss of tensile strength of the material for known mass per unit area and the condition of exposure can be evaluated for 3 months, 6 months and 12 months. The computed values of loss of strength (in %) can further be plotted on the graph paper for retained strength versus exposure period (in months) and by extrapolating this curve, the retained strength (in %) can be assessed for the desired exposure period.

4. Second Approach for Analysis of Results

The second approach is analytical solution to evaluate the UV-degradation of geotextiles/geomembranes exposed under various exposure conditions.

From Table 1, it has been observed that UV-degradation of material is function of mass per unit area and the exposure period under solar radiation.

In general,

$$Y = f(\rho, T)$$

where,

Y = retained tensile strength (in %) of material;

ρ = mass per unit area of material (in gm/m^2);

T = exposure period (in days).

Since Y varies independently with ρ and T, the variation of Y w.r.t. ρ has been drawn on graph shown in Fig. 4.

The general equation for degradation is of the form Y = mX + C.

The equation of degradation lines for different exposure period have been evaluated as,

$$\left.\begin{aligned} Y &= 0.036(\rho) + 76\ (C_1) \ldots \text{ for 3 months of exposure} \\ Y &= 0.036(\rho) + 60\ (C_2) \ldots \text{ for 6 months of exposure} \\ Y &= 0.036(\rho) + 31\ (C_3) \ldots \text{ for 12 months of exposure} \end{aligned}\right\} (1)$$

From the above equations, it has been observed that the slope of degradation line is same but intercepts on Y axis are different for different exposure period.

The values of intercept (76, 60, 31) have been plotted against the exposure period (in days) as shown in Fig. 5.

Table 1 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 1 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-stabilised	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/m^2 solar radiation
6 months = 900 kw/m^2 solar radiation
3 months = 450 kw/m^2 solar radiation
12 months = 1,800 kw/m^2 solar radiation
UV content = 6.8%
Station = Mumbai

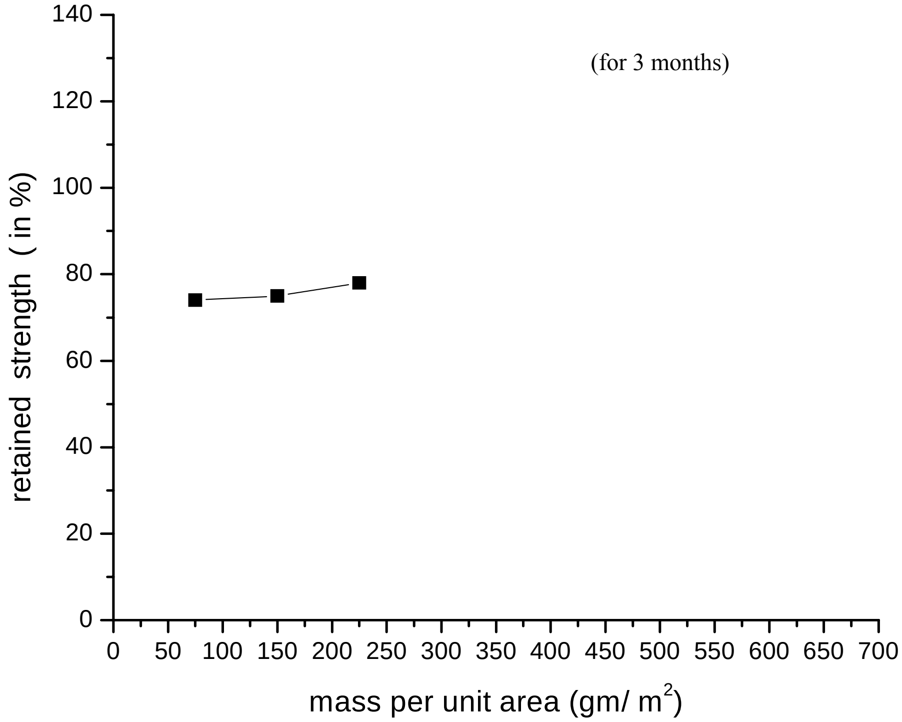
(for 3 months)
retained strength (in %)
0
20
40
60
80
100
120
140
0 50 100 150 200 250 300 350 400 450 500 550 600 650 700
mass per unit area (gm/ m2)

Fig. 1

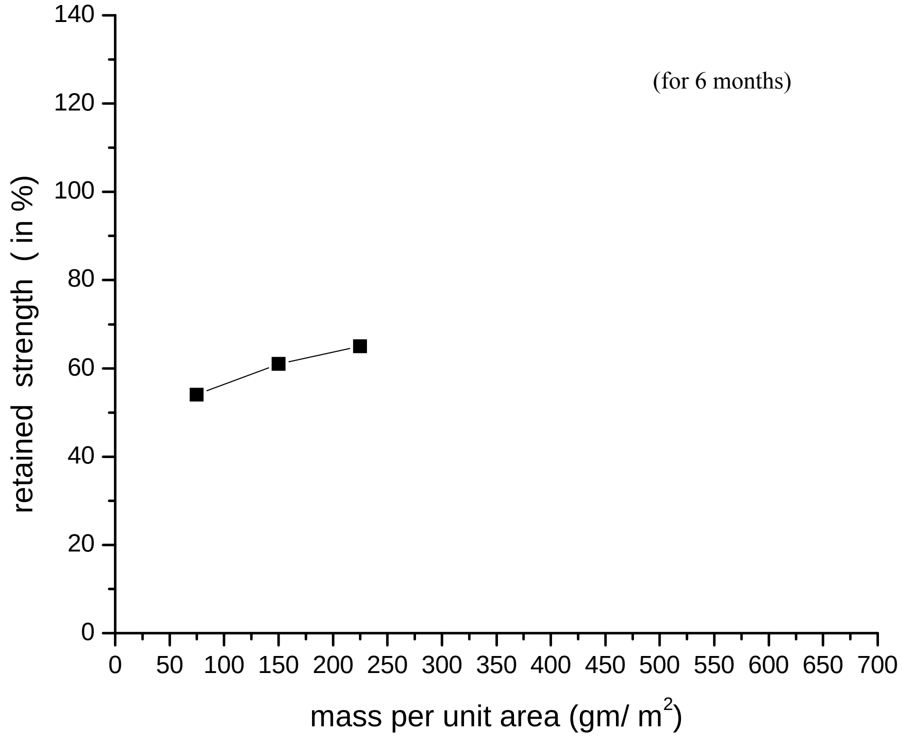
(for 6 months)
retained strength (in %)
0
20
40
60
80
100
120
140
0 50 100 150 200 250 300 350 400 450 500 550 600 650 700
mass per unit area (gm/ m2)

Fig. 2

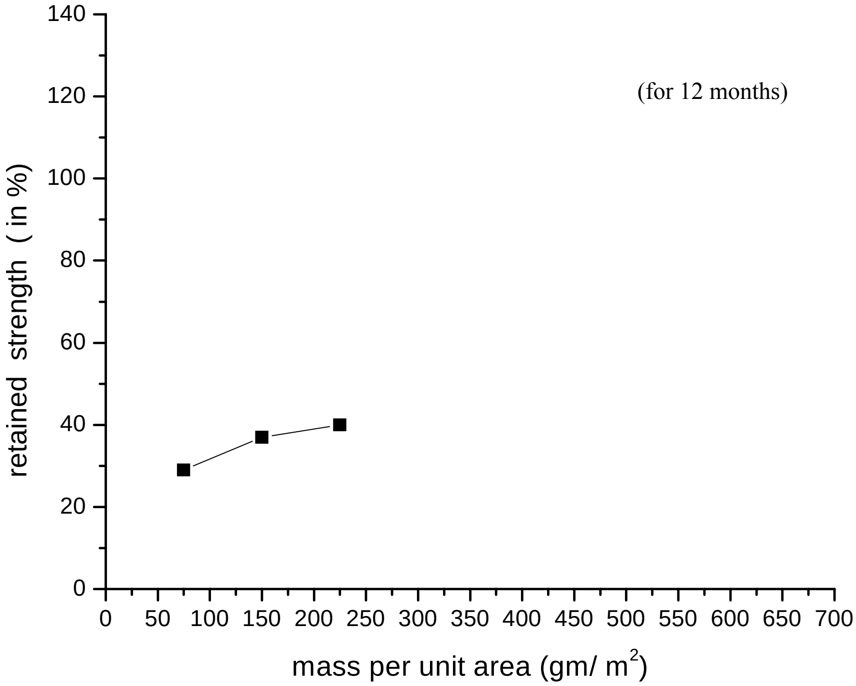

Fig. 3

Fig. 1-3 Variation of retained tensile strength w.r.t. mass per unit area of polyester freely exposed to outdoor solar radiation.

Table 2 Coefficients A, B, and C of empirical equation for UV-degradation of geotextiles/geomembranes for various conditions.

Polymer Material	Exposure period	Conditions					
		Freely exposure			Submerged in water		
		A	B	C	A	B	C
PET	3 months	-44.412	-154.709	99.269	-44.412	-154.709	104.269
	6 months	-44.383	-197.184	82.728	-44.383	-197.184	87.728
	12 months	-34.169	-230.608	53.147	-38.591	-171.994	56.577
PP	3 months	1.970	-174.676	70.726	0.507	109.088	77.983
	6 months	-28.583	-134.021	70.333	-28.583	-134.021	75.333
	12 months	-34.133	-76.4666	41.80	-40.5	-68.268	47.50
PVC	3 months	-8.979	-559.006	89.561	-.8.979	-559.006	95.561
	6 months	-16.504	-383.774	79.291	-16.504	-383.774	85.291
	12 months	-14.133	-2384.796	58.378	-14.133	-2,384.796	64.378
HDPE	3 months	-9.675	-418.772	90.303	-9.675	-418.772	97.303
	6 months	-22.059	-311.864	85.211	-22.059	-311.864	92.211
	12 months	-22.059	-311.864	59.211	-22.059	-311.864	66.211
		In contact with soil			In contact with soil and water		
PET	3 months	-44.412	-154.709	92.269	-44.412	-154.708	86.269
	6 months	-44.383	-197.184	75.728	-44.383	-197.184	69.728
	12 months	-30.434	-287.603	47.496	-30.434	-287.603	41.496
PP	3 months	1.970	-174.676	63.726	1.970	-174.676	57.726
	6 months	-28.583	-134.021	63.333	-28.583	-134.021	57.333
	12 months	-34.133	-76.466	34.80	-34.133	-76.466	28.80
PVC	3 months	-16.504	-383.774	83.291	-16.504	-383.774	78.291
	6 months	-27.040	-313.293	73.192	-27.040	-313.293	68.192
	12 months	-13.109	-822.154	46.990	-16.504	-221.310	80.044
HDPE	3 months	-30.895	-221.310	85.044	-30.895	-221.310	75.066
	6 months	-46.343	-221.310	80.066	-46.343	-221.310	75.066
	12 months	-76.089	-165.436	53.012	-157.954	-137.621	48.004

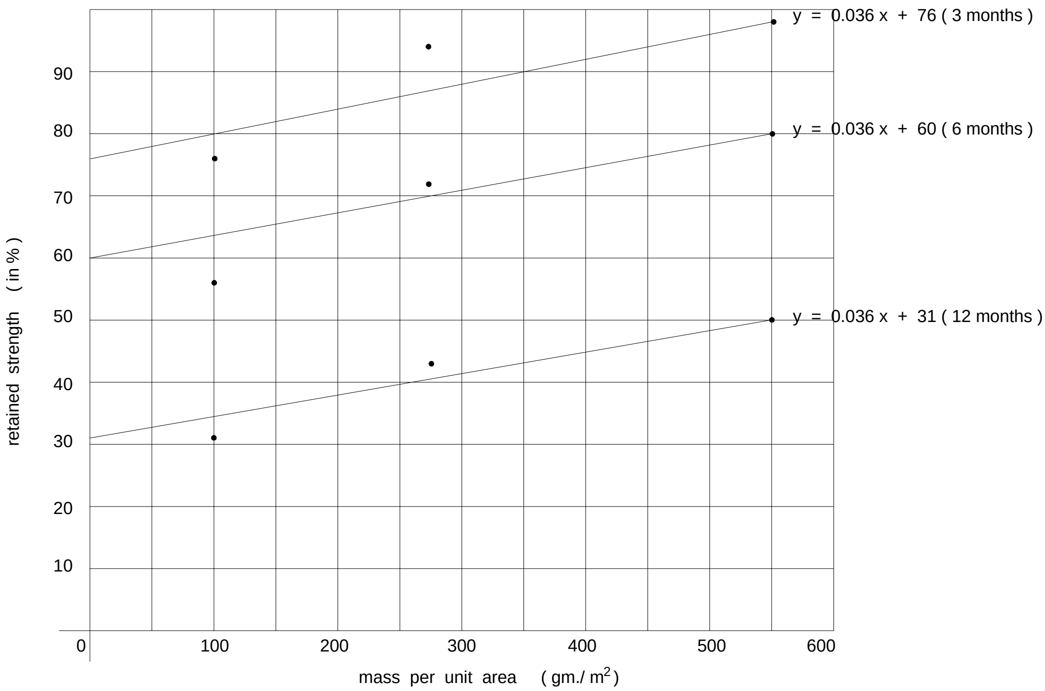

Fig. 4 Variation of retained strength w.r.t. mass per unit area of PET test specimens.

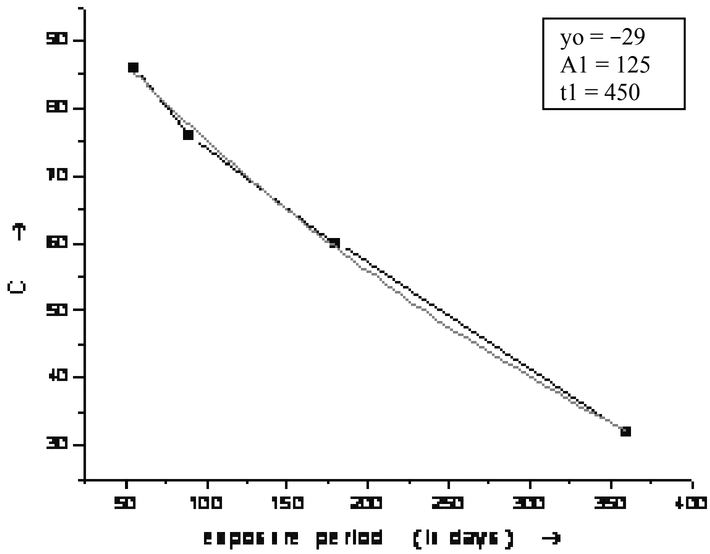

Fig. 5 Variation of "C" (interception) w.r.t. exposure period of PET test specimens.

From the Fig. 5, the equation of curve has been obtained by using software "OriginPro 7.5". The equation for PET freely exposed to UV-radiation is,

$$C = 125\ e^{(-T/450)} - 29 \quad (2)$$

by replacing the value of C_1, C_2 and C_3 by C, we get

$$Y = 0.036\ (\rho) + 125\ e^{(-T/450)} - 29 \quad (3)$$

which is the equation for retained strength of PET (freely exposed).

Similarly, degradation equations for PP/PVC/HDPE freely exposed and exposed under various conditions are tabulated in Table 3.

5. Comparison of Results of UV-Degradation

The experimentally observed values for retained strength and the computed values obtained using

Table 3 Results showing the UV-degradation equations of geotextiles/geomembranes of various mass per unit area and various outdoor exposure periods.

Test specimen	Condition	UV-Degradation equation Y = retained strength in % ρ = mass per unit area, T =exposure period (in gm/m²) (in days)
PET	Freely exposed	$Y=0.036(\rho)+125e^{(-T/450)}-29$
PET	Submerged in water	$Y=0.036(\rho)+125e^{(-T/450)}-23$
PET	In contact with soil	$Y=0.036(\rho)+125e^{(-T/450)}-35$
PET	In contact with soil and water	$Y=0.036(\rho)+125e^{(-T/450)}-41$
PP	Freely exposed	$Y=0.04(\rho)+92e^{(-T/300)}+1$
PP	Submerged in water	$Y=0.04(\rho)+92e^{(-T/300)}+7$
PP	In contact with soil	$Y=0.04(\rho)+92e^{(-T/300)}-5$
PP	In contact with soil and water	$Y=0.04(\rho)+92e^{(-T/300)}-12$
PVC	Freely exposed	$Y=0.0035(\rho)+180e^{(-T/1000)}-80$
PVC	Submerged in water	$Y=0.0035(\rho)+180e^{(-T/1000)}-74$
PVC	In contact with soil	$Y=0.0035(\rho)+180e^{(-T/1000)}-86$
PVC	In contact with soil and water	$Y=0.0035(\rho)+180e^{(-T/1000)}-92$
HDPE	Freely exposed	$Y=0.003(\rho)+190e^{(-T/1500)}-94$
HDPE	Submerged in water	$Y=0.003(\rho)+190e^{(-T/1500)}-88$
HDPE	In contact with soil	$Y=0.003(\rho)+190e^{(-T/1500)}-100$
HDPE	In contact with soil and water	$Y=0.003(\rho)+190e^{(-T/1500)}-108$

Table 4 Results showing the experimental observed values of retained tensile strength of geotextiles/geomembranes and theoretical values by UV-degradation equation.

Polymer type	Exposure period in months	Conditions							
		Freely exposure		Submerged in water		In contact with soil		In contact with soil and water	
		Experimental values	Values from second approach	Experimental values	Values from second approach	Experimental values	Values from second approach	Experimental values	Values from second approach
PET-1	3	76	77	81	83	69	71	63	65
	6	56	58	61	64	49	52	43	46
	12	31	31	35	37	26	25	20	19
PET-2	3	92	89	97	102	85	86	79	80
	6	72	71	77	82	65	66	59	60
	12	43	43	49	55	36	37	30	31
PET-3	3	98	94	99	100	91	92	85	86
	6	80	75	85	80	73	74	67	68
	12	50	47	55	52	43	44	37	38
PET-4 *	3	72	74	77	79	65	66	59	60
	6	51	55	56	61	44	45	38	39
	12	30	28	36	34	25	24	20	18
PP-1	3	74	72	79	78	67	66	61	59
	6	54	54	59	60	47	48	41	41
	12	29	31	34	37	22	25	16	18
PP-2	3	75	75	80	81	68	69	62	62
	6	61	58	66	64	54	52	48	45
	12	37	35	43	41	30	29	24	22
PP-3	3	78	78	82	84	71	72	65	65
	6	65	61	70	67	58	55	52	48
	12	40	38	46	44	33	32	27	25
PP-4 *	3	82	82	87	88	75	76	69	69
	6	69	65	74	71	62	59	56	52
	12	47	42	52	48	40	36	34	29

Notes: PET-4 and PP-4 are woven fabric. (*) The remaining test specimens are non-woven fabric. The theoretical values are based on non-woven fabric pattern. The actual retained tensile strength of woven fabric is 3% to 5% more than non-woven fabric due to continuous filament of fibers in warp and weft direction of woven fabric. Hence 3% to 5% is to be added in the theoretical values of Nonwoven fabric to obtain satisfactory results of actual retained tensile strength of woven fabric by degradation equations of Table 3.

(Table 4 continued)

Polymer type	Exposure period in months	Conditions							
		Freely exposed		Submerged in water		In contact with soil		In contact with soil and water	
		Experimental values	Values from second approach	Experimental values	Values from second approach	Experimental values	Values from second approach	Experimental values	Values from second approach
PVC-1	3	86	86	92	92	79	79	74	73
	6	75	72	81	78	68	65	63	60
	12	47	47	53	53	40	40	35	34
PVC-2	3	88	88	94	94	82	82	77	76
	6	78	74	84	80	72	68	67	62
	12	49	49	55	55	43	43	38	37
PVC-3	3	89	90	95	96	83	85	78	79
	6	79	76	85	82	73	73	68	67
	12	51	51	57	57	45	45	39	39
PVC-4	3	88	86	94	92	82	82	77	76
	6	77	73	83	79	71	71	66	65
	12	50	47	56	53	44	44	38	38
HDPE-1	3	87	86	94	92	81	81	76	75
	6	80	76	87	82	74	74	69	68
	12	54	57	61	63	48	48	42	42
HDPE-2	3	88	87	95	93	83	82	78	76
	6	82	77	89	83	77	76	72	70
	12	56	57	63	63	51	50	46	44
HDPE-3	3	90	89	97	95	85	84	80	78
	6	85	79	92	85	80	79	75	73
	12	59	60	66	66	53	53	48	47
HDPE-4	3	88	89	94	95	82	82	78	76
	6	83	79	89	85	77	77	72	71
	12	57	59	63	65	51	51	46	45

Notes: PVC-4 is UV-stabilized and the remaining test specimens of PVC are UV-unstabilized. HDPE-4 is UV-unstabilized and the remaining test specimens of HDPE are UV-stabilized. The theoretical values obtained by degradation equations of Table 4 for PVC are for UV-unstabilized and for HDPE are for UV-stabilized. Hence 2% to 3% is to be added in PVC-4 and 2% to 3% is to be deducted in HDPE-4 to get satisfactory results of actual retained strength due to presence of UV-stabilizers in the test specimens.

equation developed in the second approach have been compared. The comparison of results is shown in Table 4.

From Table 4, it has been observed that the loss of tensile strength of material observed experimentally shows fairly good agreement for loss of tensile strength obtained by "Equations for UV-degradation" i.e. first approach and "Empirical UV-degradation equations" i.e. second approach.

6. Conclusions

The analysis of results of UV-degradation for geotextiles/geomembranes shows that it is possible to evaluate the loss of tensile strength of any polymeric material used as geotextiles/geomembranes by using the equations established by above two different approaches and the life of material can be predicted prior to its intended use.

References

[1] All the references of this paper have been mentioned in the part I of this paper which is titled "Degradation of Mechanical Properties of Geotextiles and Geomembranes Exposed to Outdoor Solar Radiation under Various Exposure Conditions" published in the same journal.