Degradation of Geomembrane after Weathering Exposure

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ABSTRACT
This paper presents results of physical and mechanical tests of PVC and HDPE geomembranes that were exposed to weathering (solar radiation, humidity, wind, rain) after 6, 12, 18, 30, and 84 months under specific exposure conditions. Geomembranes of two thicknesses — 1.0 and 2.0 mm (PVC) and 0.8 and 2.5 mm (HDPE). The weathering degradation of the geomembranes was evaluated according to ASTM D1435. The results showed that the geomembranes reacted differently to the exposure. In general, the mechanical properties varied for both PVC and HDPE geomembranes. Results of puncture and tear tests showed some increases with aging. Some decreases were verified in the deformation of PVC and HDPE when submitted to weathering after the final period.

1. INTRODUCTION

In some geotechnical applications a geomembrane may be exposed for varying periods. In spite of the many advantages of geomembranes, they can degrade when in contact with sunlight. Sharma & Lewis (1994) report that geomembranes exposed outdoors may degrade and crack under prolonged exposure.

Ultraviolet radiation and elevated temperatures are very harmful to all geosynthetics. In HDPE geomembranes, for instance, oxidation degradation may occur, cutting off the molecular chains. If oxidation starts, the molecular chains continue the degradation process. This process results in a totally changed molecular structure,, a decrease in mechanical resistance, and stress cracking. In PVC geomembranes a loss of plasticizers and volatiles may occur, resulting in decreased elongation and increased brittleness. To increase the geomembranes' resistance,, antioxidant agents and UV stabilizers are added during manufacturing.

Since in many applications the duration and intensity of exposure must be taken into account, evaluating the effects of outdoor exposure is very important. Accelerated laboratory tests may be used in accordance with regulations to establish relations between outdoor and laboratory tests. This is an important aspect in evaluating the durability of geosynthetics in outdoor applications.

This paper describes the effects of puncture and tear tests on the physical and tensile properties of HDPE and PVC geomembranes that were exposed to weathering (solar radiation, humidity, wind, and rain) after 6, 12, 18, 30, and 84 months (0,5, 1, 1.5, 2.5, and 7 years).

2. WEATHERING, AGING, AND UV RADIATION

Outdoor conditions may cause drastic variations in the properties of geosynthetic material due to the effects of temperature and ultraviolet (UV) radiation. When this occurs, the degradation of polymers due to weathering manifests itself in many physical and chemical changes. These processes may occur at the same time but not at the same rate. It is difficult to evaluate plastic materials when dealing with weathering factors. The effects on the exposed material must be taken as indicative only and results of short-term exposure tests can provide an indication of relative outdoor performance.

Haxo and Nelson (1984) summarized the weathering factors affecting durability as follows: solar radiation, temperature (elevated, depressed, and cycles and fluctuations), water (solid, liquid, and vapor), and normal air constituents (oxygen and ozone).

Pierson et al. (1993) assessed the thermal behavior of geomembranes exposed to solar radiation, which induces problems (such as wrinkles) and even flaws at the construction stage when the geomembrane is still uncovered by waste. Temperatures may reach 80°C in black exposed geomembranes. Such temperatures acting on material with high coefficients of thermal expansion cause wrinkles over the entire exposed surface of the geomembrane. It was proven that a white coating applied to the surface of the membrane considerably reduces the overheating of the material. The

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use of a geotextile over a black geomembrane only delays the overheating, so this is not an appropriate means of eliminating long-term overheating.

Natural weathering tests are carried out by exposing the specimen on a suitable inert frame with a specific slope and orientation with the north axis. ASTM standards have been used as a guide in the USA and South America. After some periods of exposure, samples are taken and tensile properties are measured. Loss of these properties is taken as a measure of degradation. The time of exposure depends upon the purposes of the research. Another commonly used parameter common is global radiation from the sun. This parameter is very important in correlations with laboratory tests in that the weathering devices have been developed to accelerate weathering tests. This apparatus reproduces the spectrum of natural sun in the UV region that is very important in the aging process when dealing with polymers.

Ultraviolet radiation affects uncovered materials and can be damaging during the installation of the liner and before the placement of the waste. When geosynthetics are exposed to the combined influence of sunlight, rain, temperature, and oxygen, UV degradation can arise and the type of aging is caused by the UV content of the sunlight. Each material is sensitive to a particular wavelength (i.e. polyethylene = 300 nm, polyester = 325 nm, and polypropylene = 370 nm). The rate of aging is also determined by the temperature and humidity. The degradation mechanism is molecular bond scission (in the primary polymer's backbone) created by the sensitive wavelength within the molecular structure. Ultraviolet light causes material embrittlement and depending on the intensity of the radiation may induce cracks. Generally, degradation is noticed as a change in color and as variations in the physical properties: surface cracking and reduction of impact strength, tensile strength, and elongation (van Santvoort, 1994; Reddy & Buttul, 1998).

A way to prevent UV degradation in PVC and HDPE geomembranas is to include some additives such as carbon black and antioxidants. Carbon black is added to a geomembrane formulation mainly for ultraviolet light stabilization. The loading range of carbon black in geomembranes is typically 5 to 10% (PVC) and 2 to 3% (HDPE). Antioxidants are introduced to prevent oxidation during extrusion and to ensure long-term service life of the product. In practice, a stabilization package is often used (Fayoux et al., 1993; van Santvoort, 1994; Sharma & Lewis, 1994; Koerner, 1998 and Suits & Hsuan, 2003). Some researchers (Koerner, 1998 and Reddy & Butul, 1998) say that a good way to prevent ultraviolet damage is to keep a minimum layer (15 cm) of soil, waste, or gravel over the liner so that light cannot penetrate the material.

3. MATERIAL AND METHODS

The weathering degradation of geomembranes was evaluated according to ASTM D1435. To achieve natural aging of the samples from the effects of weather, a panel was built and located in the east-west axis. The samples are located in that way so that they receive the direct incidence of the sun for the entire day. Figure 1 show samples exposed to weathering. The exposure site is at the following geographical coordinates: 20° 22' S and Longitude: 51° 22' W. The altitude is 335 meters. Climate conditions were monitored with a microdatalogger CR-23X. The medium values obtained were 25°C (temperature), 1313 mm (precipitation), 61% (relative humidity) and 19 MJ/m^2.day (intensity of global radiation).

Geomembranes of two thicknesses were tested: 1.0, 2.0 mm (PVC) and 0.8, 2.5 mm (HDPE). The aging agents included solar radiation, humidity, wind, and rain after 6, 12, 18, 30, and 84 months (0,5, 1, 1.5, 2.5, and 7 years). Physical and mechanical tests in PVC and HDPE geomembranes were evaluated and compared to intact material. Tests were carried out according to ASTM standards: ASTM D5199 (Measuring Nominal Thickness of Geotextiles and Geomembranes), ASTM D3776 (Mass Per Unit Area), ASTM D792 (Specific Gravity and Density of Plastics by Displacement), ASTM D638 (Standard Test Method for Tensile Properties of Plastics), ASTM D4833 (Test Method for Index Puncture Resistance of Geotextiles, Geomembranes and Related Products), and ASTM D1004 (Test Method for Initial Tear Resistance of Plastic Film and Sheeting).

Figure 1. HDPE and PVC geomembrane samples exposed to weathering.

4. TESTS RESULTS AND ANALYSIS

Tests results of intact and exposed samples are presented in Tables 1 to 5. Tensile properties variations are presented in Figures 2 and 3. Tear and puncture resistances are presented in Figures 4 and 5, respectively.

Table 1. Tensile resistance.

Geomembrane	Intact		6 months		12 months		18 months		30 months		84 months	
	σ (MPa)	Cv (%)	σ (MPa)	Cv (%)	σ (MPa)	Cv (%)	σ (MPa)	Cv (%)	σ (MPa)	Cv (%)	σ (MPa)	Cv (%)
PVC 1L	18	2,5	18	2,5	18	2,7	15	1,7	17	0,6	17	0,3
PVC 1T	16	0,9	15	3,2	16	0,9	18	2,1	14,7	0,2	19	0,3
PVC 2L	17	0,7	16	5,9	17	0,7	16	0,5	16	0,8	18	1,0
PVC 2T	15	2,4	13	4,5	15	2,4	17	0,8	15	1,9	17	0,5
HDPE* 0,8L	19	2,1	19	6,1	18	5,0	16	1,5	19	1,7	20	0,4
HDPE 0,8T	20	2,9	19	8,2	17	2,3	17	8,0	19	3,8	20	0,4
HDPE 2,5L	19	5,7	20	7,4	21	5,7	20	4,3	19	1,7	21	0,6
HDPE 2,5T	20	3,8	22	7,7	20	3,2	20	3,6	19	0,5	21	0,9

Table 2. Deformability.

Geomembrane	Intact		6 months		12 months		18 months		30 months		84 months	
	ε (%)	Cv (%)	ε (%)	Cv (%)	ε (%)	Cv (%)	ε (%)	Cv (%)	ε (%)	Cv (%)	ε (%)	Cv (%)
PVC 1L	479	3,3	486	2,9	459	6,7	425	3,9	460	1,3	307	0,5
PVC 1T	520	2,1	455	6,7	520	2,1	441	1,9	478	1,3	350	0,6
PVC 2L	508	1,9	487	0,1	508	2,0	477	2,8	485	0,8	403	0,7
PVC 2T	496	2,1	462	6,7	496	2,1	467	0,9	486	3,8	446	11,3
HDPE* 0,8L	17	2,1	17	6,1	15	5,0	15	1,5	17	7,5	15	1,0
HDPE 0,8T	16	2,9	15	8,2	13	2,3	15	8,0	16	3,8	13	0,7
HDPE 2,5L	14	5,7	16	7,4	17	5,7	15,5	4,3	19	1,7	14	0,3
HDPE 2,5T	15	3,8	16	7,7	15	3,2	15,5	3,6	17,5	3,5	14	0,5

Table 3. Elasticity modulus.

Geomembrane	Intact		6 months		12 months		18 months		30 months		84 months	
	E (MPa)	Cv (%)	E (MPa)	Cv (%)	E (MPa)	Cv (%)	E (MPa)	Cv (%)	E (MPa)	Cv (%)	E (MPa)	Cv (%)
PVC 1L	7,2	1,6	7,2	1,5	7,8	9,3	8,7	1,1	7,4	1,5	28	0,2
PVC 1T	6,6	2,3	7,0	2,9	6,6	2,3	8,4	1,3	7,7	1,0	18,6	1,0
PVC 2L	5,9	3,1	6,0	0,3	5,9	3,1	7,3	1,6	6,3	1,2	12	1,3
PVC 2T	6,3	2,1	6,0	3,4	6,3	2,1	7,7	2,7	6,1	1,9	11,3	1,3
HDPE* 0,8L	332	18,9	441	6,3	493	1,9	463	1,5	434	7,5	527	0,8
HDPE 0,8T	330	17,7	484	0,7	564	1,7	554	1,2	473	3,7	600	1,0
HDPE 2,5L	406	10,2	422	1,1	378	16,7	408	6,0	373	12,4	484	1,2
HDPE 2,5T	381	10,7	462	5,6	446	0,9	366	12,7	332	6,0	484	0,3

Table 4. Results of tear tests.

Geomembrane	Intact		6 months		12 months		18 months		30 months		84 months	
	F (N)	Cv (%)	F (N)	Cv (%)	F (N)	Cv (%)	F (N)	Cv (%)	F (N)	Cv (%)	F (N)	Cv (%)
PVC 1L	53	4,6	44	2,5	53	2,0	57	3,8	55	2,1	53	1,0
PVC 1T	50	1,4	54	1,4	55	6,4	52	0,8	58	5,1	53	3,0
PVC 2L	92	2,6	96	2,0	102	2,0	104	5,0	105	4,7	100	2,0
PVC 2T	95	1,9	103	1,8	111	2,1	102	2,2	106	4,0	97	2,5
HDPE* 0,8L	126	1,7	141	2,4	133	0,8	127	2,8	137	1,6	107	2,2
HDPE 0,8T	129	2,4	134	1,3	147	2,8	129	3,1	137	0,6	115	2,0
HDPE 2,5L	338	2,9	450	1,3	464	6,4	451	3,6	385	1,0	363	1,3
HDPE 2,5T	344	2,2	435	3,7	481	3,6	439	1,3	399	0,4	387	2,2

* Values observed at yielding; CV = Coefficient of variation; L = longitudinal direction; T = transversal direction

Table 5. Results of punction tests.

Geomembrane	Intact		6 months		12 months		18 months		30 months		84 months	
	F (N)	Cv (%)	F (N)	Cv (%)	F (N)	Cv (%)	F (N)	Cv (%)	F (N)	Cv (%)	F (N)	Cv (%)
PVC 1 mm	266	2,4	356,3	3,7	377	1,9	378	4,7	362	1,4	383	1,0
PVC 2 mm	504	1,7	625	1,4	630	1,3	607	3,8	549	1,1	633	0,5
HDPE 0,8mm	389	1,8	431,4	1,8	402	2,5	404	2,9	370	4,4	419	0,6
HDPE 2,5 mm	911	1,3	946,5	1,0	960	0,9	949	0,1	861	0,3	960	0,7

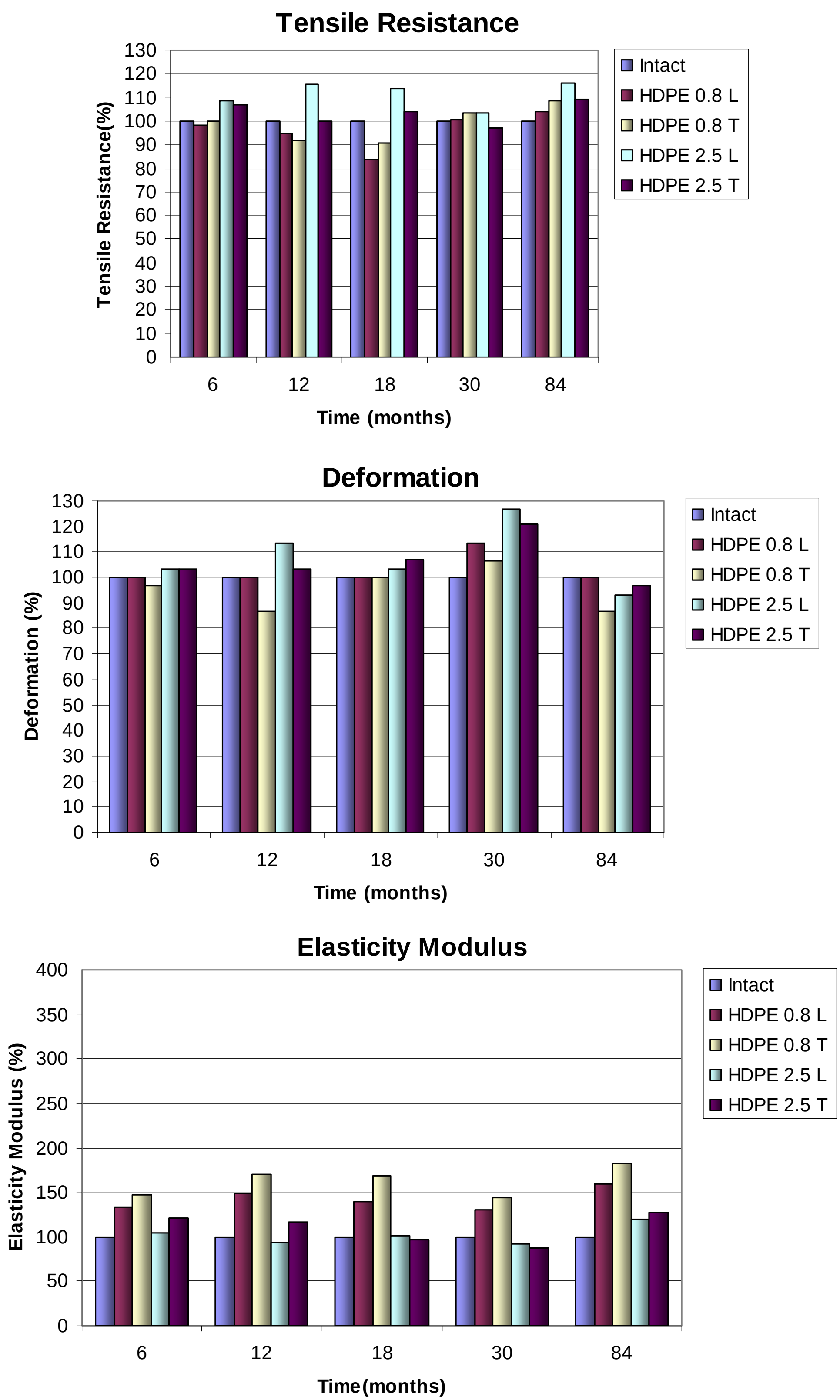

Figure 2. Tensile properties (HDPE).

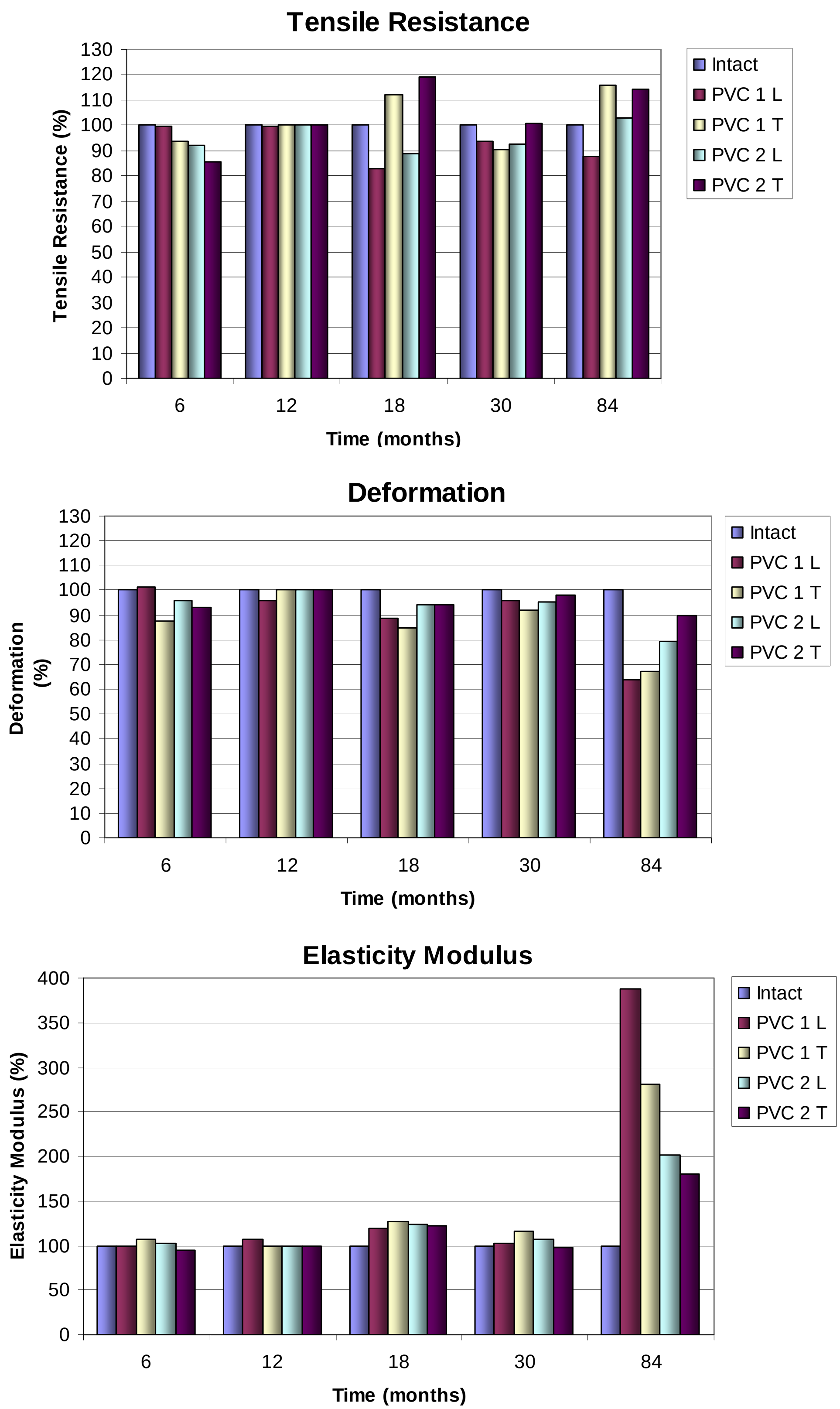

Figure 3. Tensile properties (PVC).

Physical properties showed small variations (0,5% - density, thickness, and mass per unit area). Our results showed some variations in both PVC and HDPE geomembranes after the periods of exposure. After the first periods (6 and 12 months) PVC geomembranes showed changes including alterations in tensile resistance, loss of deformation, and increases in stiffness. After the last period, increases in deformation and elasticity were very evident for PVC geomembranes (1,0 mm thickness were more affected). The samples became more rigid and stiffer than fresh samples. HDPE geomembranes showed some variations occurring in deformation, which were more significant after 30 months. By this time HDPE geomembranes showed increases in deformation and some oscillations in elasticity. The behavior was characteristic of a ductile material. However, after the last period HDPE showed an inverse behavior: the samples showed some increases in elasticity modulus and decreases in deformation.

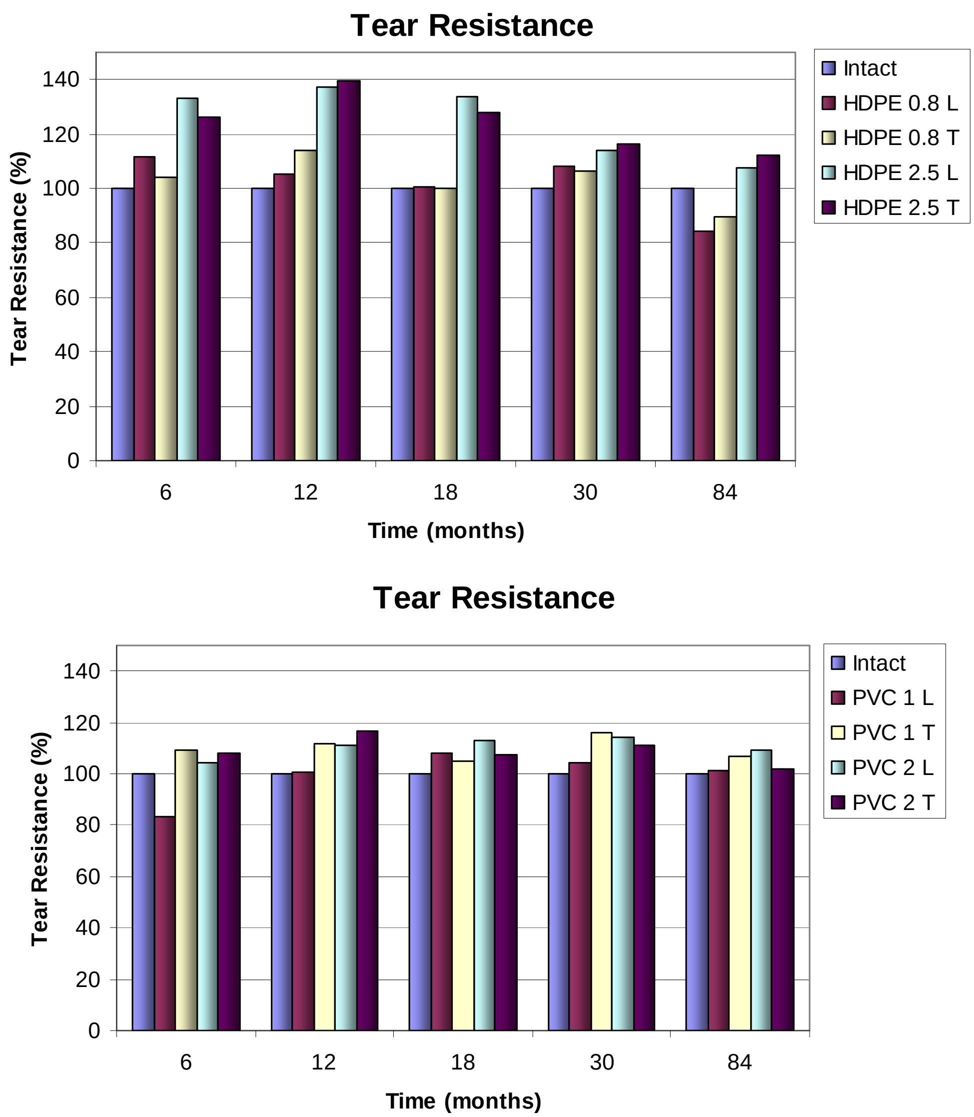

Figure 4. Tear resistance.

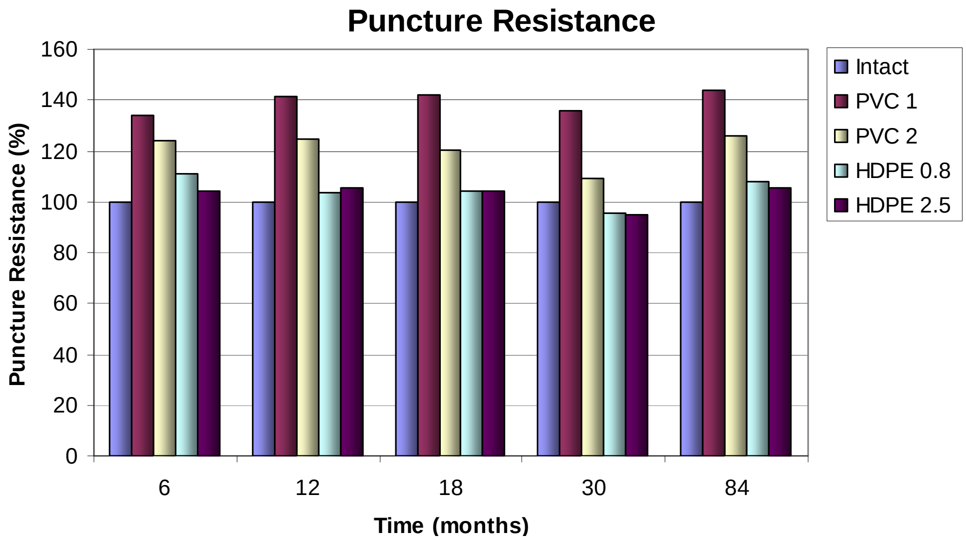

Figure 5. Puncture resistance.

Tear resistance showed some variations for both PVC and HDPE geomembranes. The PVC geomembranes showed a few minor changes in all periods. Increases in tear resistance were noted but these values were not greater than 20%. The variations in HDPE geomembranes were more significant than in PVC. Variations were nearer a 40% increase at 12 months. After 18 months the samples showed relevant variations but some decrease occurred at the last period. Interestingly, the thickest geomembranes showed the highest variations.

It appears that puncture resistance does not suffer relevant variations in the HDPE geomembranes after exposure. On the other hand, PVC geomembranes showed significant variations for the smallest thickness. Increases in puncture resistance were greater than 40% after the last period.

5. CONCLUSIONS

Results of physical and mechanical properties in HDPE and PVC geomembranes that were exposed to weathering after 6, 12, 18, 30, and 84 months were presented. In general, a few minor changes in physical properties were noted. Mechanical properties presented different behaviors during the periods of exposure. Results of puncture and tear tests showed some increases with aging. Tear resistance in HDPE geomembranes showed more significant increases than in PVC geomembranes.. However, puncture resistance suffered increases more relevant mainly in smallest thickness. Some decreases were verified in the deformation of PVC and HDPE when submitted to weathering after the final period. PVC geomembranes showed significant declines in elasticity after 7 years of exposure. The samples became more rigid than the fresh samples.

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