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Analysis of aging and degradation of HDPE and PVC geomembranes

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ABSTRACT: This paper presents results of mechanical tests in HDPE and PVC geomembranes that were exposed to different aging conditions. Geomembranes of two thicknessess were tested: 1.0, 2.0 mm (PVC) and 0.8, 2.5 mm (HDPE). The aging processes include weathering (solar radiation, humidity, wind, rain) and exposure to leachate. The results obtained show, for example, that after 4000 hours of exposure, the PVC geomembranes (1.0, 2.0 mm) were more rigid and stiffer than fresh samples. The HDPE geomembranes, on the other hand, when exposed to weathering presented increases in deformation that varied from 2% for the 0.8 mm to 14% for the 2.5 mm and when in contact with leachate become also more rigid and stiffer.

1 INTRODUCTION

A geomembrane is defined as a very low permeability synthetic membrane used with any geotechnical engineering related material to control fluid migration in a man-made project, structure, or system (ASTM D4833-88). Also called liners or flexible membrane liners, geomembranes are polymeric or bituminous synthetic sheets. They can be manufactured in different forms which include smooth or textured single layer and multiple built-up layers with or without linear reinforcement.

Geomembranes become worldwide product with many different kind of applications. Because of the diversity of chemical constituency, manufacturing methods and applicability geomembranes are truly a major category of geosynthetics requiring particular attention regarding test methods and design specifications.

The diversity of application includes works in the areas of transportation (tunnels), environmental engineering (landfills, ponds, reservoirs) and geotechnical engineering (dams, canals, railroad basis). In any case geomembranes are sealing layers which are used in substitution or in addition to other geosynthetic, compacted clay, bentonite, concrete, steel and bituminous materials.

Despite the many advantage offered by geomembranes over traditional sealing materials they can degrade when exposed to UV radiation or when in contact to aggressive stored materials, leachates and industrial refuses.

Degradation of geosynthetic materials is a multifocal problem that involves many questions outside the knowledge of the geotechnical engineering. Although the geotechnical literature provides information concerning applications, properties and positives and negatives characteristics of geomembranes, most data of aging and degradation are most suitable for northern areas. When dealing with geomembranes in tropical countries, like Brazil, for example, one must be aware of particular realities of material and weathering characteristics. The experience with aging and degradation in these countries is not yet consolidated.

Solid waste containment is powering the geomembrane market in Brazil. The largest applications in the country are related to the environmental issues but they are also applied in a diversity of engineering problems.

The lack of own researches considering Brazilian particularities and the increasing market make geomembrane applications certainly a promising field for studies and experiences be gathered. To contribute in the development of this experience in aging processes and degradation of the geomembranes in Brazil a research program is in course at the Geosynthetic Laboratory of the Department of Geotechnical Engineering at School of Engineering at Sao Carlos – University of Sao Paulo.

This article refers essentially to a study to evaluated the aging and degradation process of the Poly Vinyl Chloride (PVC) and High Density Poly Ethylene (HDPE) geomembranes. The work is still in progress and the data presented in this paper refers only to 4000 h exposure.

2 MATERIALS AND METHODS

Geomembranes of two thicknesses were tested: 1.0, 2.0 mm (PVC) and 0.8, 2.5 mm (HDPE). The aging processes include weathering (solar radiation, humidity, wind, rain) and exposure to leachate after 4,000 hours.

Mechanical tests in HDPE and PVC geomembranes that were exposed to different aging conditions were evaluated and compared to intact material. Tests were performed in accordance 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).

2.1 *Weathering Degradation*

The weathering degradation of geomembranes was evaluated according to ASTM D1435. Evaluation of the stability of plastic materials when exposed outdoors to various influences that comprise weather are complex and changeable. Because it is difficult, if not impossible, to define or measure precisely the factors directing degradation due to weathering. The results of the exposed material must be taken as indicative only and results of short-term exposure tests can provide an indication of relative outdoor performance.

To the accomplishment of the natural aging of the samples to the weather effects, a panel was built with area of approximately 25 m^2. The panel is located in the axis east-west with inclination of 22° to the north in the hourly sense, that it is the inclination where it is obtained the direct incidence of the sun on the samples along the whole day. Figure 1 show samples exposed to weathering. The place is located at the following geographical coordinates: 20° 22' S and Longitude: 51° 22' W. The altitude is 335 meters. Monitoring of climate conditions was made with a microdatalogger CR-23X. The obtained medium values were: 25°C (temperature), 1313 mm (precipitation), 61% (relative humidity) and 19 MJ/m^2.day (intensity of global radiation).

Figure 1. Panel with geomembranes exposed to weathering degradation

2.2 *Leachate exposure*

Geomembranes are increasingly being specified in containment facilities for both hazardous and municipal wastes. Materials specified for waste containment facilities must be resistant to (or compatible with) the liquids they will contact during the lifetime of the facility (White and Verschoor, 1990).

Geomembranes generally have good resistance to many different environments; however, since the chemical environments in storage and disposal facilities are site specific, it is difficult to predict accurately the ability of a geomembrane to maintain its initial properties for the lifetime of the installation solely on the basis of the manufacture's product literature. Therefore, chemical compatibility tests are performed using the actual waste liquid to which the geomembranes will be exposed (Tisinger et al., 1991).

The samples were put inside boxes of water of 1000 liters (Figure 2). Leachate was constantly circulated to avoid incrustation or deposition on the samples. Analyses were conduced with the leachate as specified in EPA method 9090.

Figure 2. PVC and HDPE geomembranes immersed in the leachate

The characteristics of the leachate are: Biochemical Demand of Oxygen (310 mg/l), Chemical Demand of Oxygen (531 mg/l), Total Solids (648 mg/l), Ammonia (33 mg/l), Total Kjeldahl Nitrogen (50 mg/l), pH (6,9) and Temperature (23°C).

3 TEST RESULTS

Figures 3 to 5 show the percentual variations observed in the tests results that were obtained with modern digital data acquisition. Results obtained for both aging conditions are listed in Tables 1 to 5. Some of the evaluated properties were: strain-stress relationship (considering yield point for HDPE), deformation, stiffness and rupture force (tear and punction tests). The values of the variation coefficient (Cv) that is defined as the ratio between the standard deviation and the average of the obtained values are also presented. Although both materials have small elastics regions, elasticity modulus have been used in many investigations as a good indication of changes in rigidity due to aging and degradation (Tisinger et al., 1991; Lauwers, 1993; Diebel, 2000; Newman et al., 2001 and Maia, 2001)

Table 1. Tensile resistance

Geomembrane	Intact		Weathering		Leachate	
	σ (MPa)	Cv (%)	σ (MPa)	Cv (%)	σ (MPa)	Cv (%)
PVC 1L	18,43	2,5	18,32	2,5	19,59	2,6
PVC 1T	16,16	0,9	15,11	3,2	15,97	1,4
PVC 2L	17,43	0,7	16,07	5,9	18,12	2,3
PVC 2T	14,66	2,4	12,53	4,5	15,28	2,3
HDPE* 0,8L	18,88	2,1	19,28	6,1	19,15	1,9
HDPE 0,8T	19,61	2,9	19,02	8,2	21,06	3,4
HDPE 2,5L	18,88	5,7	19,89	7,4	21,72	5,2
HDPE 2,5T	20,44	3,8	21,96	7,7	21,10	4,1

Table 2. Deformability

Geomembrane	Intact		Weathering		Leachate	
	ε (%)	Cv (%)	ε (%)	Cv (%)	ε (%)	Cv (%)
PVC 1L	479,3	3,3	486,3	2,9	453,3	2,6
PVC 1T	520,0	2,1	454,6	6,7	446,9	2,6
PVC 2L	507,6	1,9	487,2	0,1	451,8	3,5
PVC 2T	495,8	2,1	462,4	6,7	456,2	4,3
HDPE* 0,8L	16,85	2,1	17,19	6,1	14,83	1,9
HDPE 0,8T	16,35	2,9	14,83	8,2	12,13	3,4
HDPE 2,5L	14,16	5,7	16,18	7,4	13,48	5,2
HDPE 2,5T	15,17	3,8	15,84	7,7	14,16	4,1

Table 3. Elasticity modulus

Geomembrane	Intact		Weathering		Leachate	
	E (MPa)	Cv (%)	E (MPa)	Cv (%)	E (MPa)	Cv (%)
PVC 1L	7,245	1,6	7,215	1,5	9,103	1,5
PVC 1T	6,621	2,3	7,038	2,9	6,618	2,1
PVC 2L	5,894	3,1	6,050	0,3	7,945	2,8
PVC 2T	6,307	2,1	6,000	3,4	7,735	2,5
HDPE* 0,8L	332,2	18,9	440,9	6,3	449,3	7,7
HDPE 0,8T	330,0	17,7	483,6	0,7	511,9	9,2
HDPE 2,5L	405,6	10,2	421,6	1,1	405,6	8,6
HDPE 2,5T	381	10,7	462,3	5,6	406,3	5,4

* values observed at yielding

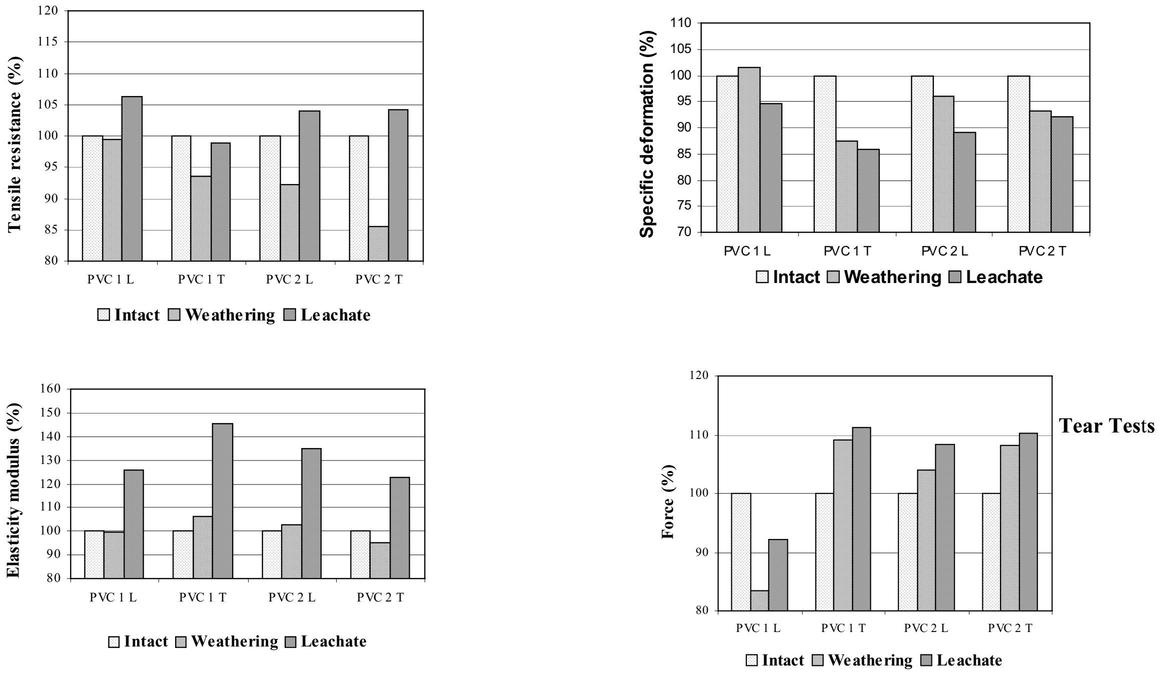

Figure 3. Results obtained in tensile tests for PVC geomembranes (1,00 and 2,00mm)

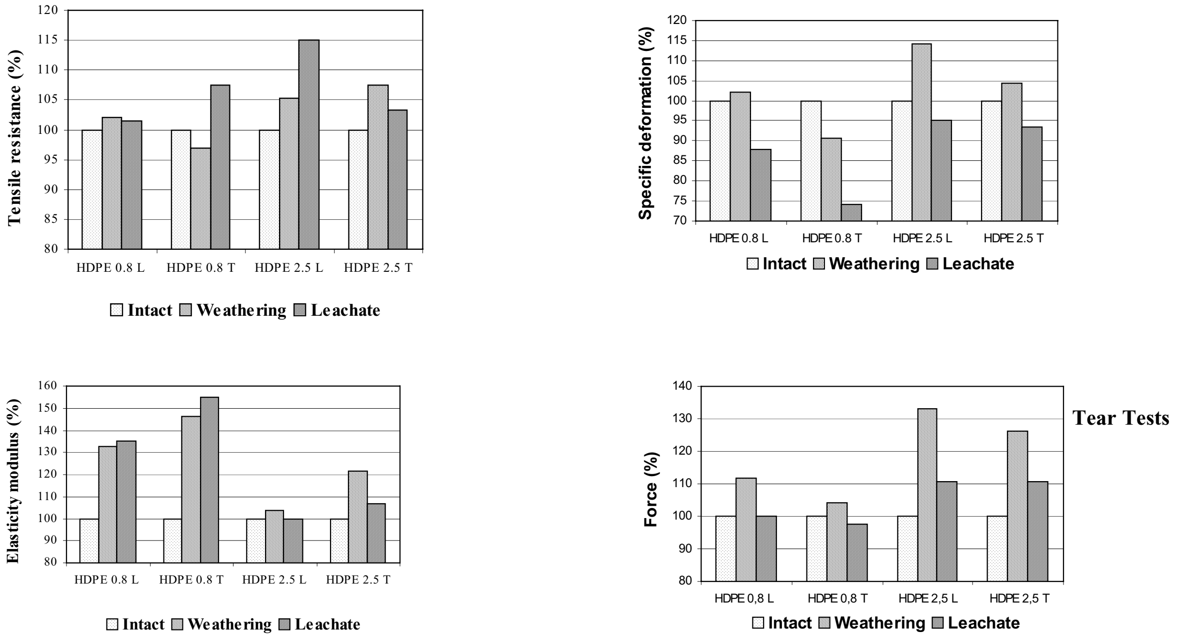

Figure 4. Results obtained in tensile tests for HDPE geomembranes (0,80 and 2,5mm)

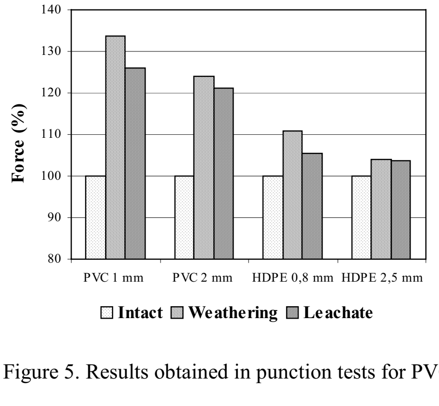

Figure 5. Results obtained in punction tests for PVC and HDPE

Table 4. Results of tear tests

Geomembrane	Intact		Weathering		Leachate	
	F (N)	Cv (%)	F (N)	Cv (%)	F (N)	Cv (%)
PVC 1L	52,54	4,6	43,83	2,5	48,41	3,7
PVC 1T	49,51	1,4	54	1,4	55,08	6,9
PVC 2L	91,91	2,6	95,6	2,0	99,67	3,7
PVC 2T	95,06	1,9	102,9	1,8	104,8	2,1
HDPE 0,8L	126,4	1,7	141,1	2,4	126,6	1,3
HDPE 0,8T	128,8	2,4	134,1	1,3	125,5	1,2
HDPE 2,5L	337,6	2,9	449,6	1,3	373,2	1,0
HDPE 2,5T	344,1	2,2	434,5	3,7	380,3	1,9

Table 5. Results of punction tests

Geomembrane	Intact		Weathering		Leachate	
	F (N)	Cv (%)	F (N)	Cv (%)	F (N)	Cv (%)
PVC 1 mm	266,3	2,4	356,3	3,7	335,4	2,6
PVC 2 mm	504,1	1,7	625	1,4	610,8	4,8
HDPE 0,8mm	388,7	1,8	431,4	1,8	409,9	2,5
HDPE 2,5 mm	910,7	1,3	946,5	1,0	944,4	1,5

3.1 *Weathering degradation*

PVC geomembranes (1 and 2mm) showed some decrease in tensile resistance in machine and transversal directions. Conversely, some increases in tensile resistance for HDPE occurred. Deformability presented decreases for PVC and some increases for HDPE. The observed stiffness for PVC decreased 4,9% (PVC 2T) and increased of 6,3% (PVC 1T). HDPE presented stiffness increases for all thickness: 32,7% (HDPE 0,8L) and 46,5% (HDPE 0,8T). Increases in punction and tear resistance were also observed.

3.2 *Leachate exposure*

PVC geomembranes presented a little decrease in tensile resistance and increases in the others samples. HDPE showed increases of 15% for HDPE 2,5L. The deformability decrease for both PVC and HDPE after the analysis period: 11% (PVC 2L), 14,1% (PVC 1T), 12% (HDPE 0,8L) and 25,8% (HDPE 0,8T). As excepted the HDPE 2,5L did not present variation in stiffness, the other membranes became stiffer. Observed increases of 22,6% (PVC 2T), 25,6% (PVC 1L), 34,8% (PVC 2L), 45,3% (PVC 1T), 35,2% (HDPE 0,8L) and 55,1% (HDPE 0,8T) were reached. Similarly to the variation that occurred when submitted to weathering, some increases were noted for tear and punction resistance for both PVC and HDPE.

Properties like thickness, density and mass per unit area didn't show significant modifications for both weathering and leachate exposures.

In general was observed that the tear resistance presented the largest variations for HDPE 2,5T (26%) and HDPE 2,5L (33%) when subjected to weathering. In this sense, variations registered in punction tests for PVC 1mm were 34% in weathering and 21% in leachate. Some increases in strain-stress relationships were also verified for PVC (6% to PVC 1L, 4% to PVC 2L and PVC 2T in leachate). HDPE presented the largest variations (15% to HDPE 2,5L in leachate and 7% to HDPE 2,5T in weathering). In terms of deformability it was observed some decreases in PVC for both leachate and weathering.

4 CONCLUSIONS

In general, the mechanical properties varied for both PVC and HDPE geomembranes. Results of punction and tear tests showed some increases with aging. Some increase was also verified in the deformation of HDPE when submitted to weathering. Conversely, the deformation decreases for PVC geomembranes. The geomembranes were more rigid and stiffer than fresh samples.

Geomembranes when in contact with leachates or weathering show a lost of additives that may occurs and the properties mechanicals can present, in particular situations, some variations (see for example, Tisinger et al. 1991, Koerner 1998, Maia 2001 and Lodi 2002). Evidently, a number of factors can influence the performance of the geomembranes. Analysis more specifics should be performance to evaluation of properties like permeability, diffusion and chemical properties. In this sense, investigations like TGA, DSC, DMA and IR must be considering (see Halse et al., 1991).

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