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The influence of some urban waste degradation agents on the mechanical properties of geomembranes

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ABSTRACT: Geomembranes are widely used as a component of liner systems in sanitary landfills. The performance of geomembranes depends on their ability to maintain their properties under the many actions that they are subjected to. This paper deals with the behavior of HDPE and PVC geomembranes when acted by some degradation agents present in urban waste landfill. Exhumed; immersed in leachate and exposed to 75° C of temperature membranes were tested in tension and compared with the behavior of virgin membranes. It is shown that all the degradation agents have modified the tensile properties of the tested geomembranes to some extent. In the leachate immersed membranes and in those exposed to 75° C of temperature, the variation of rupture stress of PVC and yield stress of HDPE and corresponding strains were in the range of ±10%, beyond 6 months of incubation. Some thermal tests (TGA and DSC) were also performed in order to qualitatively explain the variation observed in the test results.

1 INTRODUCTION

Disposition of all kind of residue is a topic of major concern all over the world. Many strategies such as the reduction, the reuse and the recycling of waste and alternative techniques, such as incineration, have been devised to deal with the problem and to reduce the amount of waste that must be disposed in the environment. Sanitary landfill is a waste containment system where sanitary and environmental concepts are taken into account to avoid the contamination and pollution of foundation soil, subsurface and surface water and air as well as the spread of diseases. Apart from the sanitary and environmental concerns a sanitary landfill must be seen as an engineering structure. So it must offer safety against many actions such as stress and displacements on the waste body, cap system and foundation soil as well as slope stability, among others.

Many parts compose a sanitary landfill. In conjunction with the waste or cell bodies, it is necessary to provide internal drainage for gas and leachate, intermediate cover of waste cells, system collection of leachate and of gas, final cap and surface drainage, among others.

A crucial component of any sanitary landfill is the liner system. The liner is a barrier that has the primary function of avoid leachate to reach the foundation soil and sub surface water. Compacted soils have been the first option used as soil liner. However, the expanding offer of synthetic materials has changed this scenery. These include the geomembranes and the geosynthetic clay liners. All these options can be solely used, but arrangements that include the combination of some of them, together with other draining soils or geosynthetics can be adopted and are recommended by some regulations.

Geomembranes are thin sheets of polymeric materials that are almost impermeable to liquids and gases. They are composed of different polymers and, depending on the resin being used, some additives can be incorporated to improve some properties such as the UV resistance or the deformability. Two of the most used are High Density Polyethylene (HDPE) and Polyvinyl chloride (PVC). During storage, transport, installation and lifetime, a geomembrane is subjected to many physical and chemical actions and to various types of stress.

The choice of a geomembrane for a specific application rests on factors such as the mechanical resistance and chemical resistance to the leachate components and the permanence of these properties during lifetime (Sharma & Lewis, 1994; Koerner, 1997; Peggs & Thiel, 1998). Many examples of chemical incompatibility of various geomembranes are available in the literature, as well studies about the variation of some properties with time of exposure to temperature, UV radiation or biological activity, among others (Tisinger et al., 1991; Tsuboi et al., 1991; Koerner & Eith, 1998).

This paper is a contribution on the subject of geomembrane degradation. Its main objective is to study the degradation of mechanical properties of HDPE and PVC Brazilian geomembranes when exposed to typical conditions of a municipal sanitary landfill. The results of tensile tests of virgin and exposed specimens were compared and some thermal tests (TGA and DSC) were also performed in order to explain some of the observed behavior.

2 TESTS PERFORMED

Two samples of HDPE geomembranes and one of PVC were used. The HDPE samples came from two manufacturers and were identified as sample A and B. PVC and HDPE geomembranes of different thickness (1 and 2mm for PVC and 1 and 1.5mm for HDPE) were submitted to tensile tests, in machine and transversal directions, according to ASTM D638 – Standard Test Methods for Tensile Properties of Plastics. They were also submitted to tear resistance (ASTM D1004) and puncture resistance (ASTM D4833) and all these samples had their thickness measured according to ASTM D 5199. The tests were performed in the geomembranes on their virgin state and after exposure to degradation agents, namely: a) geomembranes exhumed from an municipal solid waste (MSW) experimental landfill after 18 months of construction; b) geomembranes immersed in leachate from MSW and c) geomembranes exposed to 75° C of temperature. In addition to these tests, Thermogravimetric Analysis (TGA) was performed for the PVC and Differential Scanning Calorimetry (DSC), for the HDPE. However, due to space limitations only the stress strain behavior in the longitudinal direction, as observed in tensile tests, will be addressed in this paper, as well as the thermal tests. Sometimes, the values in the transversal or cross machine direction will be mentioned for comparison. The stress strain curves from tensile tests allow calculating the modulus of elasticity. However this is a property difficult to calculate considering, among other reasons, the judgmental errors in defining the values of interest. In spite of these limitations and just for qualitative comparison, some results of modulus are presented.

3 TEST RESULTS

3.1 *Virgin samples*

Figure 1 shows typical stress strain curves of tensile tests on virgin samples of HDPE (A and B) and PVC, both 1mm thick. As can be seen, HDPE shows a yield stress for about 17% of strain. After that, the stress decreases but soon it increases with strain until an ultimate or break value reached for values larger than 800% of strain. Regarding PVC, it can be seen its ductile behavior. The rupture occurs to strain of about 600%. Table 1 summarizes average results of tensile tests, including the elasticity modulus. σ for the HDPE geomembrane must be seen as the yield stress and the rupture stress for the PVC. The break parameters for HDPE (σ_b and ε_b) are also presented. When comparing samples A and B, it can be seen that yield and break stresses of sample B are larger than that of sample A; also, strain associated to yield is larger for sample A

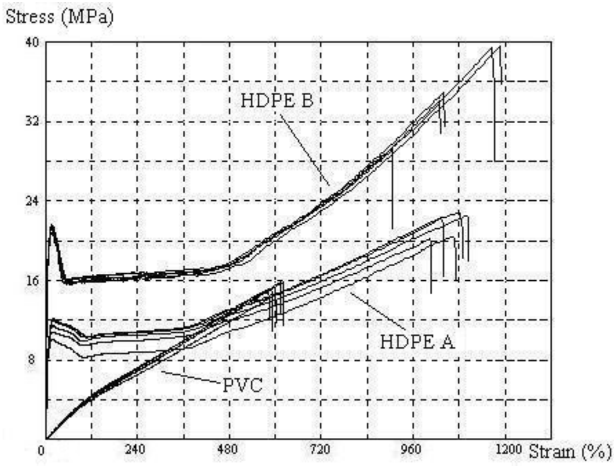

Figure 1. Stress strain curves of the tested geomembranes, 1mm thick.

Table 1: Average results of tensile tests (ASTM D 638) on PVC and HDPE geomembranes, both 1mm thick, in the machine or longitudinal direction.

Average Results	σ MPa	ε (%)	E MPa	σ_b MPa	ε_b (%)
PVC 1,0 mm - Long	15.3	601.2	4.0	-	-
PVC 2,0 mm - Long	16.9	481.4	6.4	-	-
HDPE 1,0 mm – Long A	11.4	20.4	181.0	21.7	1058
HDPE 1,5 mm – Long A	13.1	17.8	243.4	21.7	969
HDPE 1,0 mm – Long B	21.2	16.1	466.6	35.4	1066
HDPE 1,5 mm – Long B	20.4	15.3	491.9	32.2	1129

Figure 2 show the thermograms from DSC tests for the HDPE geomembranes. It is known that HDPE shows a single melting point at about 128º C (Halse et al., 1991). Both samples, A and B have shown this feature. However, sample A shows double melting points, one at about 113º C and the other at about 128º C. Two factors can cause double melting points in polyethylene. One can be associated to the blending of polymers of different molecular weights. The other can be related to the recrystallization of polymer during thermal analysis. The presence of double melting points in sample A probably is due to the presence of materials with different molecular weights which can justify the lower values measured in tensile tests, as compared to sample B.

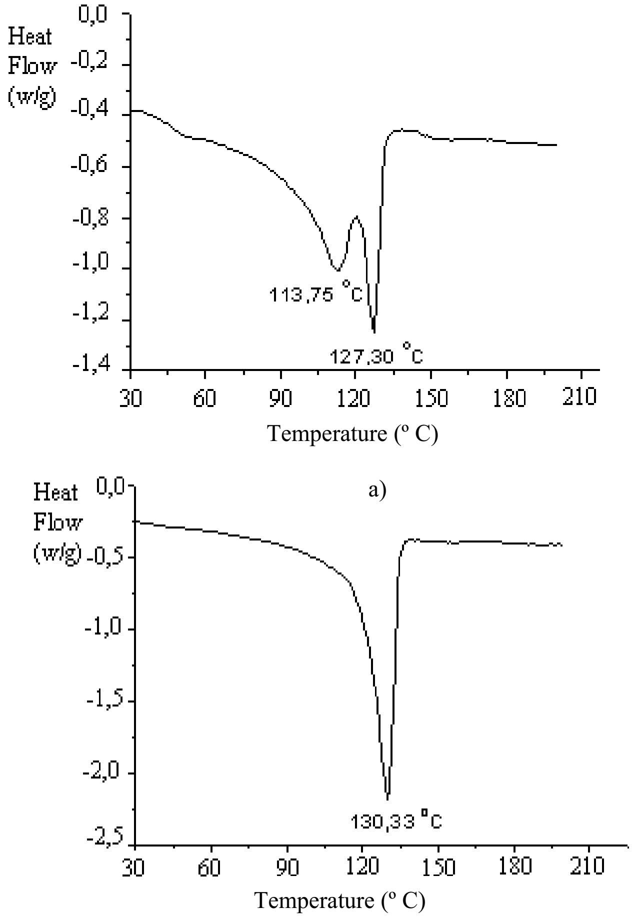

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Figure 2: DSC thermogram of samples HDPE geomembranes. a) sample A; b) sample B.

Figure 3 shows the thermogram of PVC as obtained in Thermogravimetric analysis. The results are typical of PVC. There are two decomposition processes occurring at about 260º C and 432 º C. According to Halse et al. (1991), the first process encompass the dehydroalogenation to form polyenes and the degradation of plasticizers, that responds for about 71% of the weight of the tested sample. The second process is the degradation phases of polyenes and totals about 18%. In this test, air was not introduced to oxidize the carbon black and polymer residue.

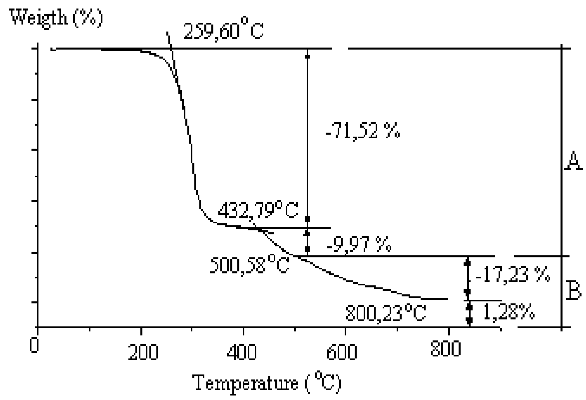


Figure 3: TGA thermogram of PVC geomembranes

3.2 *Samples from the Experimental Landfill*

Figure 4 shows stress strain curves of PVC geomembranes tested in the machine direction. Curves V are of virgin samples, while curves F are of the samples exhumed from experimental sanitary landfill after 18 months. As can be seen, there is some hardening in the samples from the fill, which is reflected by an increase in the rupture stress and a decrease in the corresponding strain. The rupture stress has increased about 33% in the machine direction. Although not shown here, this variation was 46% in the cross machine direction. The associated strains has decreased by 22% and 26%, respectively. The modulus of elasticity has shown larger variations, which reflect both the variations measured and the variability associated to its determination. There was an increase of about 160% in the machine direction and of about 220% in the transversal direction. However, in spite of these variations it can be observed that the exhumed membrane still preserves its ductile behavior. Results from TGA from virgin and exhumed samples didn't allow observing any significant difference between both samples, considering the first decomposition process which includes dehydroalogenation and loss of plasticizers. This means that an eventual loss of plasticizer could not be detected in this case. Variation in the test procedure, stopping the heating at the melting temperature of the plasticizer (about 200^o C) perhaps could measure small loss of plasticizer.

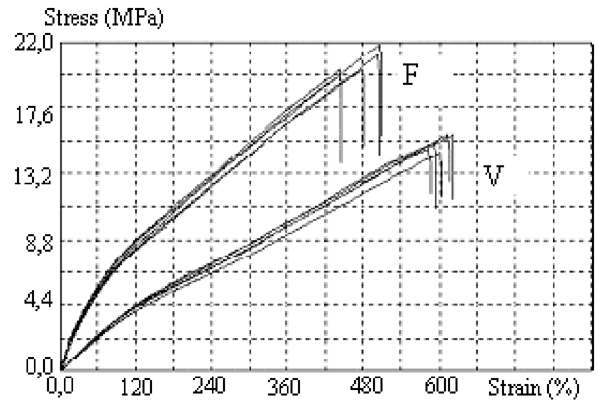


Figure 4: Stress strain curves from tensile tests on virgin and exhumed PVC samples.

As far as the HDPE geomembranes are concerned the stress strain curves are not shown, but it is worth to say that they have shown small variations in the measured properties. The variation didn't exceed 8% of the corresponding value of the virgin sample.

3.3 *Samples immersed in leachate*

Table 2 summarizes the tensile properties of both HDPE, sample A, and PVC geomembranes before and after immersion in leachate from urban waste for 5 and 8 months. After sampling, membranes were kept wet and tested within 24h after removal from leachate. Only before molding the specimens for test, the membranes were gently washed, using tap water, to remove residues.

The main components and chemical characteristics of leachate were Chemical Oxygen Demand 7780 mg/l and Biological Oxygen Demand, 4588 mg/l; the organic acids were Acetic (181 mg/l), Propionic (1925 mg/l) and Isobutyric and Butyric (both lower than 10 mg/l). The organic Nitrogen was 460 mg/l, while the amoniacal Nitrogen was 564 mg/l. Fe, Zn and Mn were 64.05; 2.44 and 5.06 mg/l, respectively. Total solids were 10058 mg/l and volatile solids, 5656 mg/l.

Table 2: Tensile properties of HDPE and PVC geomembranes before and after immersion in leachate from urban waste.

Average Results	σ MPa	ε (%)	E MPa	σ_b MPa	ε_b (%)
Before immersion					
PVC 1,0 mm - Long	16.0	527.8	5.9	-	-
PVC 2,0 mm - Long	16.52	501.5	5.8	-	-
HDPE 1,0 mm – Long A	11.4	20.6	181.0	21.7	1058
HDPE 1,5 mm – Long A	13.1	17.85	243.4	20.7	1070
After 5 months of immersion					
PVC 1,0 mm - Long	15.5	499.3	6.15	-	-
PVC 2,0 mm - Long	16.8	479.0	6.6	-	-
HDPE 1,0 mm – Long A	11.9	22.0	160.6	18.5	834
HDPE 1,5 mm – Long A	12.8	18.8	204.6	19.8	968
After 8 months of immersion					
PVC 1,0 mm - Long	15.0	484.6	6.0	-	-
PVC 2,0 mm - Long	15.6	478.7	5.8	-	-
HDPE 1,0 mm – Long A	10.9	22.3	188.3	20.2	990
HDPE 1,5 mm – Long A	12.7	19.3	234.6	17.3	747

As can be observed, excepted for 1.5mm HDPE, after 8 months of immersion, HDPE, sample A, and PVC showed small variations (in the range of ± 10%) in the measured properties and it was not noticed any appreciable influence of membrane thickness in the variations observed.

3.4 *Samples exposed to 75^o C of temperature*

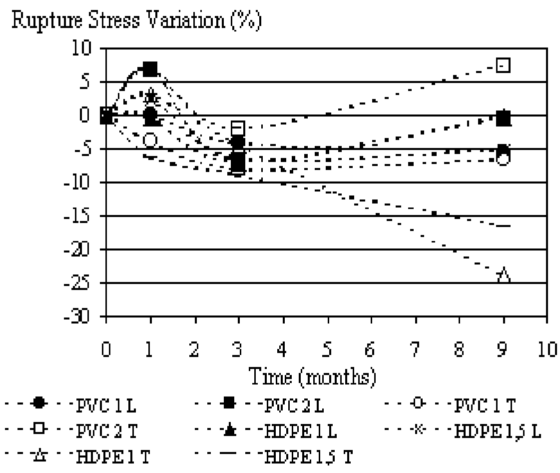
Figure 5 shows the variation of tensile behavior of PVC and HDPE geomembranes with time of exposure. The HDPE is from manufacturer A. In this figure the results related to the machine direction (represented by L) and to the cross machine direction (represented by T) are presented. As can be seen there is not a defined trend of variation with time. The rupture stress of PVC and the yield stress of HDPE and corresponding strains have reached their maximum variation after one month of exposure. This variation reduced as time increased. The PVC rupture stress has varied by an amount of about ±5% and the corresponding strain reduction was inferior to 10%, after 9 months of exposure. A similar behavior was observed for HDPE, sample A, regarding yield stress and corresponding strain. However larger variation in yield stress of HDPE was observed in this sample in the cross machine direction.

Regarding the membrane thickness it was not possible to observe any defined trend of variation, since its influence was erratic.

Break stress for HDPE has reduced until three months and then recovered some of its initial strength at nine months of exposure. The largest variation was observed in the cross-machine direction. The corresponding break strain (not shown here, due to space limitations) has also reduced in a similar way as break stress, but at nine months it has reached the values corresponding to the virgin sample.

Just for illustration, it is worth to say that the modulus of elasticity of both materials (results not shown here) was the property that varied the greatest amount. For instance, the modulus of PVC 1mm thick was reduced by 20%, while the modulus of HDPE 1mm thick has increased by 15%, after 9 months of exposure.

Finally it is worth saying that all the specimens subjected to mechanical tests had their thickness measured. It was observed that the influence of the degradation agents in the thickness of the samples was negligible, since the variations observed were lower than 1%, variation that could be credited to the test variation.



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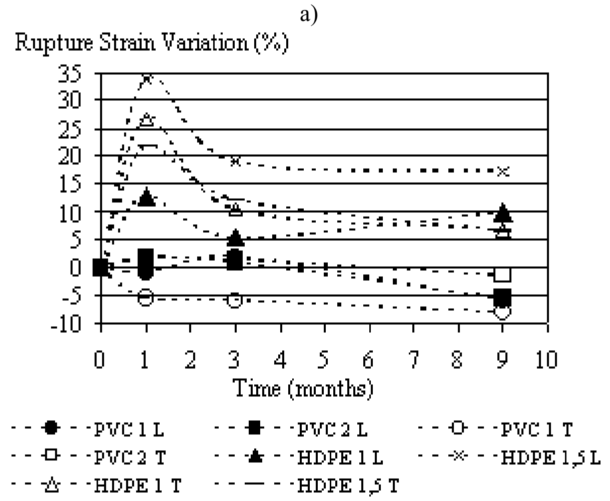

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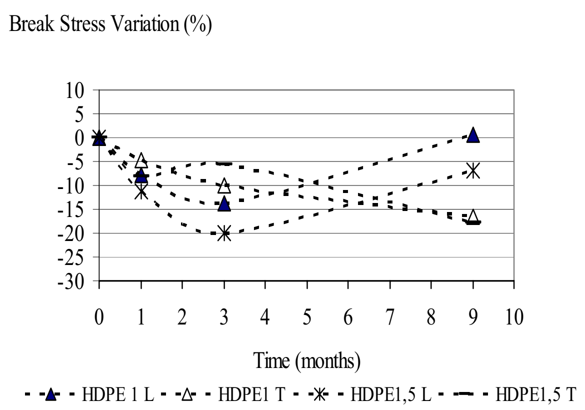

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Figure 5: Variation of tensile properties of HDPE and PVC membranes after exposure to 75o C of temperature. a) rupture or yield stress; b) rupture or yield strain; c) break stress for HDPE.

4 CONCLUSION

This paper has presented the preliminary results of degradation of HDPE and PVC geomembranes when subjected to some degradation agents present in urban waste landfill. It was observed that after 18 months of use in a landfill, PVC geomembrane 1mm thick hardened a little bit but still conserved its flexibility, while the HDPE geomembrane 1mm thick, from manufacturer A, showed small variation, inferior to 8%, on tensile properties. TGA tests on PVC couldn't identify an eventual loss of plasticizer in the exhumed membrane.

HDPE sample B showed larger values of tensile properties than sample A and this behavior probably was related to the blend of materials with different molecular weight in the composition of sample A, as suggested by DSC thermogram that showed double melting points in this sample.

Leachate immersed samples of HDPE, sample A, and PVC showed small variations (in the range of ± 10%) in the measured properties. However the variation in yield stress of HDPE was larger in the cross machine direction.

The temperature changed the tensile properties with time of exposure, but a consistent trend of variation couldn't be established. After one month of exposure, the variation of both PVC and HDPE properties reached their maximum, but this variation reduced as time increased. The PVC rupture stress has varied by an amount of about ±5% and the corresponding strain reduction was inferior to 10%, after 9 months of exposure. A similar behavior was observed for HDPE, sample A, regarding yield stress and corresponding strain. However larger variation in yield stress of HDPE was observed in this sample in the cross machine direction. Break stress and corresponding strain for HDPE have reduced until three months and then recovered some of its initial strength and corresponding strain at nine months of exposure. The largest variation was observed in the cross-machine direction.

None of the variations observed could be associated to the variation of the thickness of the samples, since the variation observed was negligible, lower than 1%, which is within test variation.

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