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Durability of LDPE Geomembrane within Sealing System of MSW (landfill)

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Abstract**—**Analyse of locally manufactured Low Density Polyethylene (LDPE) durability, used *within* lining systems at bottom of Municipal Solid Waste (landfill), is done in the present work. For this end, short and middle time creep behavior under tension of the analyzed material is carried out. The locally manufactured material is tested and compared to the European one (LDPE-CE). Both materials was tested in 03 various mediums: ambient and two aggressive (salty water and foam water), using three specimens in each case. A testing campaign is carried out using an especially designed and achieved testing bench. Moreover, characterisation tests were carried out to evaluate the medium effect on the mechanical properties of the tested material (LDPE). Furthermore, experimental results have been used to establish a law regression which can be used to predict creep behaviour of the analyzed material.

As a result, the analyzed LDPE material has showed a good stability in different ambient and aggressive mediums; as well, locally manufactured LDPE seems more flexible, compared with the European one. This makes it more useful to the desired application.

Keywords**—**LDPE membrane; solid waste; aggressive mediums; durability

I. Introduction

IT is interesting to note that environmentalists frequently claim that technical materials, specially used in landfill's lining systems, are bound to fail in a relatively short time. "Failing" is practically defined as developing a leak".

Recently, in practice, the lifetimes of HDPE geomembranes in landfill lining systems have been variously estimated to be until 200 years. At the other end of the scale installed HDPE lining systems in other applications, typically exposed pond liners or cast-in concrete liners, have not lasted 6 months without failing.

Among many HDPE geomembrane liners that have “failed” in the past 20 years, all have failed in a very limited number of ways, but none have just “worn-out” or generally degraded to nothing, nor is it expected that they will. However, practical experience with HDPE geomembranes is limited to about 25 years. Polyvinyl Chloride (PVC) has been evaluated after 30 years, and polypropylene (PP) is quite young at about 10 years.

Many EPA 9090 immersion testing [ASTM D-5167] have been performed with Municipal Solid Waste leachates and none have been shown to damage the geomembrane – the degradative effect of MSW leachate on HDPE can practically be ignored [1], [2].

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It is frequently affirmed that the only meaningful parameter that requires specification for HDPE is its stress cracking resistance (SCR). This is the only parameter that reflects the wide range of mechanical durabilities of geomembranes made from the different HDPE resins [3].

All other index properties (tensile, puncture, and tear) are essentially identical in all HDPE geomembranes. Fortunately, as a result of the failures that have occurred, resins, geomembranes, and welding equipment and/or procedures used in landfill lining systems have significantly improved [4].

LDPE and PP do suffer from Super Critical fluids, but only when their antioxidants are depleted and they oxidize. Certain polymers can get to be hydrolyzed, by chains cutting of, leading to their embrittlement; others can only fixing water molecules (weight growing) [5], [6].

Such failures have been more evident in exposed lining systems in ponds, lagoons, and concrete basins where restrained contraction stresses are cyclic as temperatures change, where the geomembrane is not confined between two layers, where leakage is more evident, and where the damage can be seen [7].

However, HDPE and PP have cracked on wrinkles under a hydrostatic head and there has recently been cracking in reinforced PP on the underside of floating covers at the bottom of drainage troughs.

The nature of stress and load applied to the geomembrane requires them to be some flexible and deforms according to CET conditions. For this purpose, they must present a relatively low modulus of deformation and good absorption and resistance to delayed deformations (creep).

Strength yield of recently tested LDPE membrane, representing a great practical characteristic, had reached about 8 MPa with respect to ambient temperature of 20°C and velocity of 25 mm/min [8]. This yield can be improved by adding plasticizers. The creep modulus is obtained of about 7 to 15 MPa for 1000 hours of time under a same ambient temperature [9].

Beside conducted experimental analysis to predict the creep behavior of analyzed material, it is possible to develop mathematical model using obtained experimental results.

Panoplies of works have been considered different models to predict a creep behavior of plastics and polymers, as linear and exponential laws [10].

Originality of presented work is a carried out creep tests on LDPE specimens under tensile load but simultaneously immersed in various aggressive medium (salty and soaped waters). As control specimen, an immersed one in drinking water has been previously tested.

To this end, a device, presented later, has been specially designed to accomplish the fixed tasks. A mechanical characterization is finally achieved to evaluate the effect of aggressive environment toward LDPE mechanical properties.

II. Testing and Materials

A. Materials

In order to predict the effect of currently used LDPE in aggressive medium, the following testing campaign is carried out: First, specimens of two kind of LDPE were tested to fix their mechanical characteristics, especially strength under tension; the used kinds of textile are: locally manufactured, LDPE of Skikda (Algeria) and European, LDPE-CE using appropriate standards [11]. Secondly, the two kind of LDPE, placed simultaneously in salty and soapy aggressive medium, were tested under a traction creep. Finally, a second characterisation test is carried out to evaluate the effect of aggressive middle (salty) and compared to these of a normal ambient medium (Fig.1).

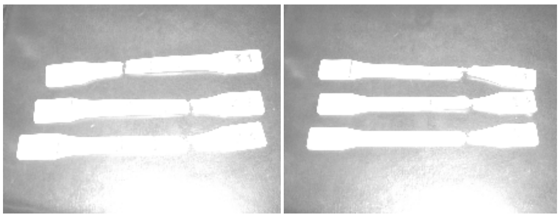
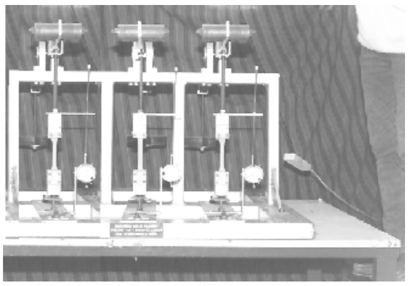


Fig. 1 Photos of tested LDPE specimens

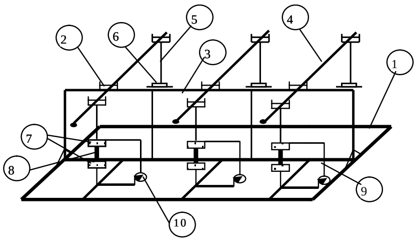
B. Description of a testing machine

In order to accomplish this task, a design and fabrication of an experimental stand (device) is carried out in a Mechanical Engineering Laboratory of USTHB University (Algiers) (Fig.2) [12].

The testing machine (fig.2a), with a cinematic scheme (fig. 2b), is conceived in order to achieve a creep test using 03 specimens, simultaneously. The machine is compound by: a base (1); articulation (2) ; a frame support (3); loading handle (4); loading plates (5); loading masses (6); Jaws (7); specimens (8); adjustment rods (9) and comparators (10).



a)



b)

Fig. 2 Designed testing machine photo

III. Experimental Handling

A. Initial characterization of both materials

Initially, both (local and CE LDPE) materials must be tested to evaluate their behaviour and stiffness under tension. The locally manufactured LDPE seems less rigid than a European (CE) one, presenting a low strength yield with, respectively, a high rupture deformation. Figure 3 shows allure of this behavior.

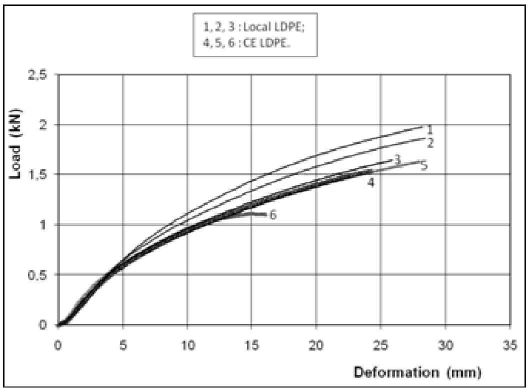


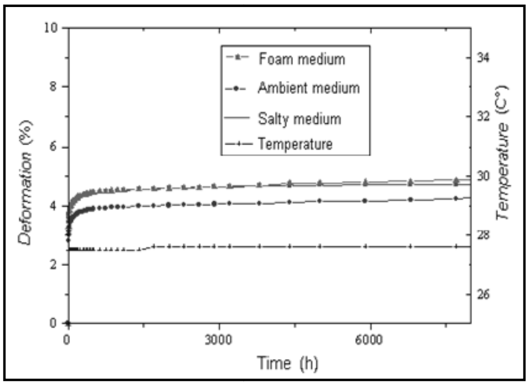
Fig. 3 Initial characterization of materials

B. Middle time creep test

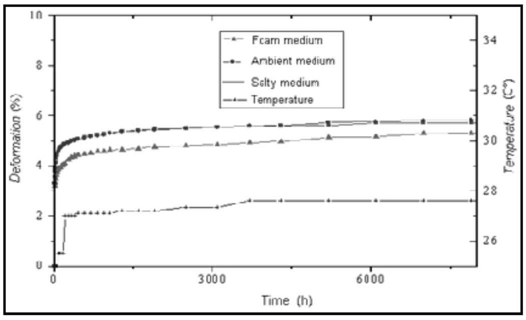
After specimen's placing in the testing machine, comparators were fixed and loads released. Once time is fixed we begin a displacements record with respect to time.

Three specimens in different mediums were tested under 03 identical loading cases (5; 7,5 ; 10 daN). Figures 4a, b and c show middle-time (about 03 months) testing results.

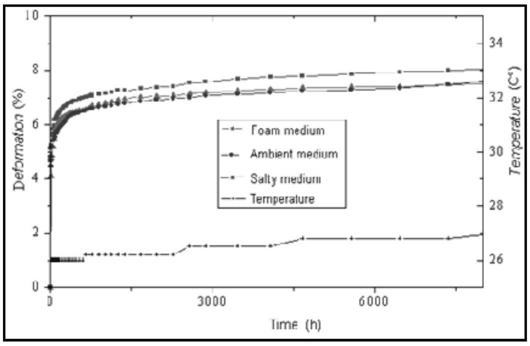
At the end of first step test, we remark that during the beginning, displacements are very fast. For this reason, we decided to manage for a short time creep test, trying to master and control this step of testing.



a)



b)



c)

Fig. 4 Middle-time creep test curves.
a) Load of 5 dN; b) Load of 7,5 dN; c) Load of 10 dN

C. *Short time creep test (2h)*

Test results are illustrated in fig. 5, for a more suspected aggressive medium. Obtained results show a same behaviour for specimens immerged in different mediums. After an instantaneous deformation witch, differs from each loading case to another, creep curves match a slow evolution and tend toward to stabilize. This observed difference between curves for different mediums is probably due to a local disparity of material physic characteristics.

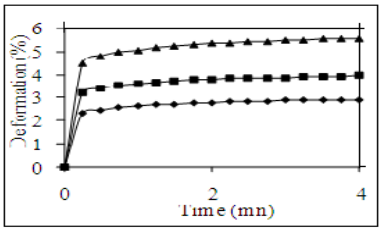


Fig. 5 Short-time creep curves for a foam middle

D. *Characterisation of tested specimens*

Through obtained results, we can conclude that no medium, expect the salty one, has an effect on creep behaviour of tested polyethylene, at least, for a short and a middle time conditions. To prop up this conclusion, a characterisation tests will be carried out on previously tested specimens.

Hover, as the salty middle seems to be a more influent on the creep behaviour, only tested specimens in the so-called middle will be a subject to the characterisation tests (Tension test). Thus, three (03) specimens are tested; tests are conducted with a speed about 100 mm/min.

Results of obtained mechanical characteristics are consigned in table I.

TABLE I
MECHANICAL CHARACTERISATION OF TESTED LDPE UNDER CREEP TESTING

Concentr - ation degree (%)	Test number	Limit of elasticity, R_e (MPa)	Tension Strength, R_m (MPa)	Failure deformat - ion, ε_R (%)	Elasticity Modulus, E (MPa)
	1	9,25	12,28	79	132,87
100	2	9,75	13,06	61,50	129,7
	3	9,54,	12,68	75,5	156,39
Average value		**9,51**	**12,67**	**72**	**139,65**
	1	9,53	12,21	70,04	136,48
50	2	9,81	12,82	73	143,28
	3	9,79	12,62	77,5	148,95
Average value		**9,71**	**12,55**	**73,51**	**142,90**
	1	10,97	12,83	67,53	129,55
25	2	9,87	12,86	74	143,25
	3	10,29	13,2	79	139,19
Average value		**10,37**	**12,96**	**73,51**	**137,33**

IV. MODELLING OF LDPE CREEP BEHAVIOUR

A. *Regression low determination*

The LDPE creep testing results were used to develop a helpful model for predicting short-time and middle-time creep behaviour. Experimental campaign can lead to the experimenting plan resumed by presented bellow table II.

TABLE II
EXPERIMENTING PLAN OF EXPERIMENTAL CAMPAIGN RESULTS

Load, σ (d N)	Time, t (s)	Deformation, ε (%)								
		Ambient medium			Soaped medium			Saline medium		
		Test 1	**Test 2**	**Test 3**	**Test 1**	**Test 2**	**Test 3**	**Test 1**	**Test 2**	**Test 3**
	0	3,10	3,15	3,00	3, 05	3,10	3, 05	2,72	2,75	2,75
	1000	4,50	4,50	4,25	4,40	4,50	4,55	3,87	3,90	3,90
	2000	4,55	4,52	4,35	4,55	4,60	4,60	4,00	4,05	4,10
	3000	4,60	4,62	4,50	4,65	4,70	4,65	4,05	4,10	4,15
5	4000	4,65	4,65	4,55	4,70	4,72	4,70	4,10	4,12	4,17
	5000	4,70	4,70	4,60	4,75	4,75	4,72	4,12	4,15	4,20
	6000	4,72	4,72	4,70	4,77	4,72	4,75	4,15	4,17	4,22
	7000	4,75	4,75	4,75	4,80	4,77	4,80	4,17	4,18	4,25
	8000	4,77	4,80	4,80	4,82	4,80	4,90	4,20	4,20	4,27
	0	3,50	3,50	3,45	3,50	3,50	3,52	3,35	3,40	3,37
	1000	5,10	5,12	5,00	5,27	5,30	5,35	5,55	5,60	5,45
	2000	5,40	5,45	5,30	5,57	5,60	5,62	5,67	5,70	5,50
	3000	5,60	5,60	5,40	5,65	5,70	5,65	5,70	5,80	5,60
7,5	4000	5,65	5,65	5,60	5,70	5,72	5,70	5,75	5,82	5,72
	5000	5,70	5,75	5,65	5,75	5,75	5,75	5,82	5,85	5,80
	6000	5,72	5,80	5,70	5,80	5,80	5,85	5,85	5,90	5,85
	7000	5,75	5,82	5,72	5,82	5,82	5,87	5,90	5,95	5,92
	8000	5,80	5,85	5,77	5,85	5,85	5,90	6,00	6,05	6,05
	0	4,60	4,62	4,60	4,02	4,05	4,05	4,40	4,40	4,42
	1000	7,10	7,15	7,10	6,70	6,75	6,70	6,57	6,60	6,60
	2000	7,20	7,22	7,20	7,10	7,10	7,15	6,65	6,70	6,77
	3000	7,40	7,40	7,40	7,30	7,30	7,30	6,77	6,80	6,82
10	4000	7,60	7,57	7,60	7,40	7,45	7,40	6,85	6,90	6,87
	5000	7,70	7,75	7,70	7,50	7,50	7,45	7,00	7,05	7,00
	6000	7,75	7,77	7,75	7,55	7,55	7,55	7,05	7,10	7,10
	7000	7,80	7,85	7,80	7,65	7,60	7,65	7,10	7,15	7,20
	8000	7,85	7,87	7,85	7,70	7,65	7,70	7,15	7,20	7,22

Let’s suggesting a regression equation with a following shape:

$$\varepsilon(t) = \beta_0 + \beta_1\sigma + \beta_2\, \ell n\, t + \beta_3\, \sigma\, \ell n\, t + \beta_4 x_1 + \beta_5 x_1\sigma + \beta_6 x_1 \ell n\, t + \beta_7 x_1 \sigma\, \ell n\, t + \beta_8 x_2 + \beta_9 x_2\sigma + \beta_{10} x_2 \ell n\, t + \beta_{11} x_2\sigma\, \ell n\, t + \beta_{12} x_1x_2 + \beta_{13} x_1x_2\sigma + \beta_{14} x_1x_2 \ell n\, t + \beta_{15} x_1x_2\, \sigma\, \ell n\, t. \quad (1)$$

Where:

β_i : searched coefficients;

σ and t : quantitative variables of loading and time respectively.

x_1 and x_2 : qualitative variables for two aggressive mediums respectively ;

ε : observed creep-deformation variable;

Considering Fisher criterion to fix non significant parameters and by rejecting termers which have influence on creep-deformation less than 0,95 % obtained above equation can be simplified and taking form :

Using a minimum square method and estimation criterions, we can determine β_i coefficients, then explicit form of predicting equation become:

$$\varepsilon(t) = 2 + 0{,}2\, \sigma - 0{,}00007\, \ell n\, t + 0{,}04\, \sigma\, \ell n\, t + 3\, x_1 + 0{,}09\, x_1\sigma + 0{,}00008\, x_1 \ell n\, t + 0{,}04\, x_1\, \sigma\, \ell n\, t - 0{,}7\, x_2 + 0{,}1\, x_2\sigma + 0{,}0001\, x_2 \ell n\, t + 0{,}08\, x_2\sigma\, \ell n\, t. \quad (2)$$

$$\varepsilon(t) = 2 + 0{,}2\, \sigma + 0{,}04\, \sigma\, \ell n\, t + 3\, x_1 + 0{,}09\, x_1\sigma + 0{,}04\, x_1\, \sigma\, \ell n\, t - 0{,}7\, x_2 + 0{,}1\, x_2\sigma + 0{,}08\, x_2\sigma\, \ell n\, t. \quad (3)$$

Finally, by fixing the value of a given x_i term equal to 1, and putting equal to null other terms, we can obtain the predicting equation of creep behaviour for each case of aggressive medium.

However, the equation according to the ambient medium will take the following form:

$$\varepsilon = 2 + 0{,}2\ \sigma + 0{,}04\ \sigma\ \ell n\ t. \quad (4)$$

For the foam medium:

$$\varepsilon = 5 + 0{,}29\ \sigma + 0{,}08\ \sigma\ \ell n\ t. \quad (5)$$

And for the salty medium:

$$\varepsilon = 1{,}3 + 0{,}3\sigma + 0{,}12\ \sigma\ \ell n\ t. \quad (6)$$

B. Plotting of separately established regressions:

In this paragraph, for each type of considered mediums, some curves were plotted using the obtained regression law. Actually, three levels of axially applied stress were considered, so: 1 MPA, 2 MPA and 3 MPA. (Figs. 6, 7 and 8)

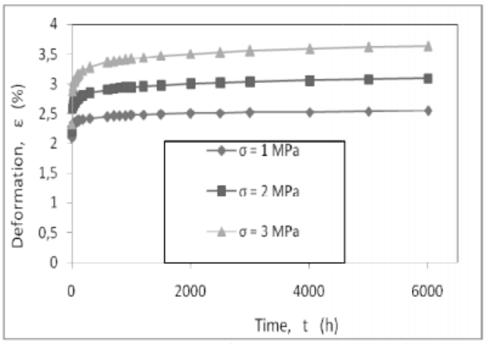


Fig. 6: Middle-time creep curves for various values of axial stress "σ". (Ambient medium)

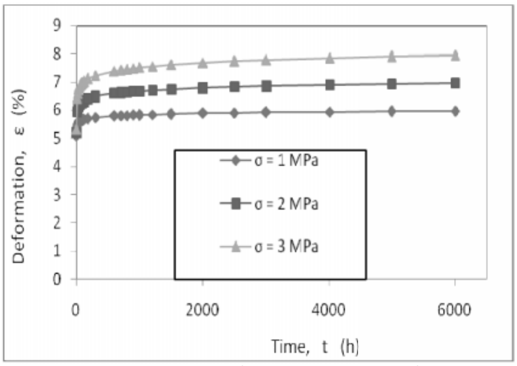


Fig. 7 Middle-time creep curves for various values of axial stress "σ". (Foam medium)

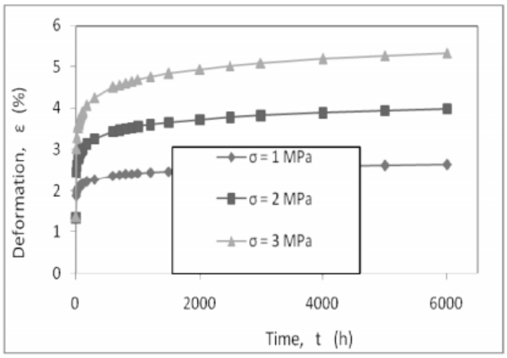


Fig. 8 Middle-time creep curves for various values of axial stress "σ". (Salty medium)

C. Interpolation of separately established regressions:

Since the difference between curves for different medium (eqs. 3, 4 and 5) is sufficiently small 03 curves of three obtained regressions, for each medium, they can be fitted and transformed on an unique law giving an unique curve to predict creep (durability) behaviour of tested LEPD membrane; let's assume the wished form of searched expression:

$$\varepsilon = \beta_0^* + \beta_1^*\ \sigma + \beta_2^*\ \sigma\ \ell n\ t. \quad (7)$$

Where: β_0^*, β_1^* and β_2^* searched coefficients of a new synthesis law :

So, after fitting calculus, a representative law takes the following form:

$$\varepsilon = 3 + 0{,}25\sigma + 0{,}1\ \sigma\ \ell n\ t. \quad (8)$$

Figure 9 will show and simulate the creep behavior for LEPD membrane used in lining system of CET. It is clearly showed that initially deformation for the developed general regression is about 3 %; also, the regression shows a limitation for zero value of applied axial stress "σ".

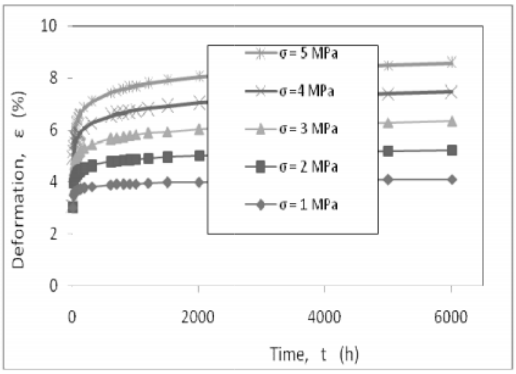


Fig. 9 Middle-time creep simulation for various values of axial stress "σ". (All mediums)

V. Conclusion and Perspectives

Obtained results by the present study allowed us affirming that, LDPE membrane is not chemically sensitive to aggressive medium, at least in the short and middle-times.

In addition, the following important points can be highlighted:

- The locally manufactured LDPE seems less rigid than a European (CE) one, presenting a low strength yield with, respectively, a high failure deformation; this makes it more useful to the landfill's requirements.
- Both testing mediums, a soapy as well as a salty have neglected effect on short and middle-time creep behavior of tested LDPE;

Furthermore, results obtained through creep tests have been exploited to develop a practical regression law, to predict a creep behavior of LDPE under various values of axial applied stress;

Besides, following perspectives and recommendations can be stated:

- Thermoplastic materials can present a good choice in a marine environment (density close to that of sea water) but we must take precautions to compare them based on design criteria;
- In the office, we will use important safety factors on the mechanical parts or between games to reflect their evolution in time.
- For use mechanical parts, do not hesitate to make use of thermoplastics more "technical" than traditional PVC and PA. The characteristics of LDPE are very promising.

Acknowledgment

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