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Characterization and modeling of the residual deformations in the polyethylene pipes with a high density of gas transport

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Abstract

In this paper, we present an experimental approach on the study of the evolution of residual deformations through the wall of polyethylene pipes- HDPE 80 on the mechanical behavior on one hand, and on the other hand, on the effect of chemical agents present in the soil and which can enter into interaction with the embedded tubes. The results indicate that the polyethylene is highly influenced by the presence of acids and solvents that degrade it. The modeling of constraints and residual deformations obeys to very different equations in comparison with those governing the solute shaping.

1. Introduction

The development of polymers is related to their mechanical properties, which themselves depend on the microstructure. Thus, the semi-crystalline polymers have mostly high toughness that meets the products requirements to withstand severe conditions (impact, creep, fatigue). Among these materials, a high-density polyethylene receives double concerns for many years [1].

Worldwide and in Algeria, high-density polyethylene resins (HDPE) are transformed into large scales tubes and connectors to build transmission networks and distribution of natural gas in cities.

EP systems support the effects of soil movements due to instabilities and large temperature variations. Because of their good resistance to cracking, the PE pipes have a high degree of reliability under normal usage conditions. Under these conditions, their life is estimated at more than 50 years on the basis of regression curves constructed from accelerated essays of hydraulic pressure [2].

The mechanical properties depend largely on the material's constitution that is to say not only on its chemical composition, but also on the organization of the various phases present (their size, shape, distribution) so, on its microstructure [3].

The description of the mechanical properties of PE has been widely discussed in literature. For example, many studies are devoted to the complete characterization of the uniaxial traction curve and detailed explanation of its various features, certain properties such as the rate of natural deformation still to be thoroughly explored [4].

These properties can be influenced by the action of chemical agents, solvents act as plasticizers, and because they increase the distance between these strings, the value of the material modulus elasticity decreases [3].

Thanks to the paraffinic nature of the molecule, the polyethylene is extremely resistant to water; the water absorption at room temperature is negligible.

Polyethylene is susceptible to oxidation, especially in the presence of ultra-violet rays. Prolonged exposure to heat further accelerates oxidation, with considerable deterioration of the electrical and mechanical properties and of the aspect [5]. Stress Corrosion Cracking (SCC), which results from strongly coupled thermo-mechano-chemical processes, and sensitive to material composition and morphology, frequently causes a dramatic reduction of the lifetime of polymer pipes. SCC in thermoplastics usually starts as a microcrack network within a layer of degraded polymer adjacent to the pipe surface exposed to a combined action of mechanical stress and chemically aggressive environment. SCC is a common problem for metals, polymers and composites that serve under a combination of mechanical stress and chemical degradation in aggressive environment [14, 15].

In technical applications, the deformation is a much more important factor for plastics than other materials. The designer should be familiar with the mechanical behavior of polymer materials not to exceed the maximum constraints permitted to avoid disruptions. As with most materials, a simple traction-elongation curve will be a good base element to know the mechanical behavior of such plastic or polymer.

Over time and according to the manner of use of plastics, there is often a change of their properties, which can cause the products' deterioration. The aging of plastics is manifested by degradation, often slow but always irreversible to their properties. The effects of this degradation arise from the notion of "lifetime" of the material, that is to say, the time required for a property (physical, chemical or electrical) reaches a threshold below which the material becomes unusable [3].

The aim of this work is to study the interaction of some chemical environments with high-density polyethylene pipes for water distribution and transport, based on the test results of uniaxial traction.

2. Experimental Study

2.1. Material and Samples Preparation

The treated material is used for the production of pipes for gas distribution; they are of Algerian production (Sonalgaz). These tubes have an external diameter of 125mm and 101mm inside and a SDR (Standard Dimension Ration) of 11. They have the following properties:

The technique of samples preparation involves cutting the tube by a universal turn varying the advancement in the longitudinal direction. To hold the tube during machining, wood chuck is prepared to be followed by the tube. The used

cutting tool is from steel and 1.8 mm thick. To minimize the effect of the resulting heat cutting, the selected speed was 45 rpm. The selected samples have the form of rings of the same width.

Table 1. Mechanical and Thermal Properties of the Polyethylene used in the tests [6].

Property	Value
Density (g/cm ³)	0,95
Absorption of water (on 24h basis)	< 0,01%
Coefficient of thermal expansion (10 ⁶ K ⁻¹)	100-200
Coefficient of Poisson	0,46
Friction coefficient	0,29
Rockwell hardness (shore)	D 60-73
Tensile modulus (GPa)	0,5-1,2
Impact resistance, IZOD (J/m)	20-210
Traction Resistance (MPa)	15-40

2.2. Experimental Procedure

Table 2. Different Chemical Environments.

Chemical environment	Number of test pieces
1% HCL	2
10% HCL	2
20% HCL	2
1% H ₂ SO ₄	2
10% H ₂ SO ₄	2
20% H ₂ SO ₄	2
Crude oil	2
Toluene methanol	2
Distilled water	2
Free air	1

The tests presented in this section have been made in the LR3MI University of Annaba. The samples prepared from the gas tube, they were cut along a generator, and impregnated in the chemical environments shown in Table 2 to determine the effect of this later on the mechanical properties of the material and residual deformations according to time.

The first measurement of deformations was carried out after half an hour of cutting and impregnation in the chemical environments with a transparent and flexible millimeter ruler to conform the shape of the curvilinear sample (Figure 1 and 2).



Figure 1. Millimeter Strip.



Figure 2. Gas Sample.

3. Results

Internal constraints are the highest just after their appearance and therefore the most dangerous for the finished pieces. The fact that the internal constraints lead or not to the breaking process, it depends on the result of external forces and internal constraints that relax over time. No rupture occurs if the sum of the constraints submitted by the piece throughout all its life remains, at all times, less than the creep resistance or durability of the material [7, 17].

The modeling of these residual constraints and deformations obeys to very different equations in comparison with those governing the solute shaping. Between two successive instants, the constraint increment $\Delta\sigma$ and the deformation increment $\Delta\varepsilon$ are related by the following equation:

$$\Delta\varepsilon = \frac{1+\nu}{E} \Delta\sigma + \left(3\Delta p \frac{\nu}{E} + \alpha \Delta T \right) l \quad (1)$$

Where Δp is the variation of the internal pressure, ΔT is variation of the temperature and l is the length of the pipe.

The Poisson coefficient ν , the Young's modulus E and the coefficient of expansion α of course depend on the temperature, but they can also depend on time (relaxation phenomenon), and the crystallization and orientation of the macromolecules that can be heterogeneous between the skin and the heart of the piece [8, 18].

The results of the deformations of the samples in the form of rings are determined from the relationship between the variation of the outside diameter of the sample and the initial outer diameter. The deformation at the instant $t = t_i$ is then expressed by the following relationship:

$$\varepsilon_{t_i} = \frac{D_{t_0} - D_{t_i}}{D_{t_0}} \quad (2)$$

Where D_{t_0} and D_{t_i} are the outside diameter of the sample at time $t = 0$ (initial time) and at time $t = t_i$, respectively.

Figure 3 reports the deformation rate evolution with time, we note that the curves of different samples have the same pace, and the deformations start right after cutting so at time $t = t_0$. These curves have a similar appearance to that obtained for the typical curves of creep $\varepsilon = f(t)$ Semi-crystalline visco-elastic materials encountered in the literature [9, 10].

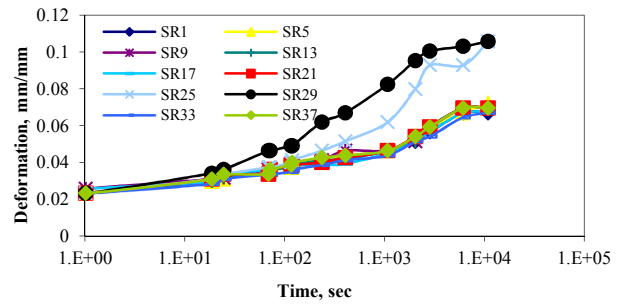


Figure 3. Evolution of tube samples deformations HDPE 80 to 18 months treated in different chemical environments.

Where SR1, SR9, ... is number of specimen ring used in the tests.

The behavior of samples under the effect of residual constraints illustrated by the deformation curves as a function of time as shown in Figure 3 is described by the following two mathematical models that have been selected among other models:

$$\varepsilon = A \cdot t^n \quad (3)$$

and

$$\varepsilon = B + C \cdot \ln(t) \quad [10] \quad (4)$$

Where t is the elapsed time in seconds while n , A , B , and C are specific parameters to the polyethylene material obtained by processing the measured deformations. The values of these parameters for each test are given in Table 3. They are obtained by statistical treatment of results of 18 months of observation. According to the coefficients of determination, it is found that the trend is very good.

During the measurement of the deformation's rate ($d\varepsilon / dt$), which is defined as the first derivative of the deformation with respect to time. It has been found that the latter decreases with time and tends to be canceled as shown in Figure 4.

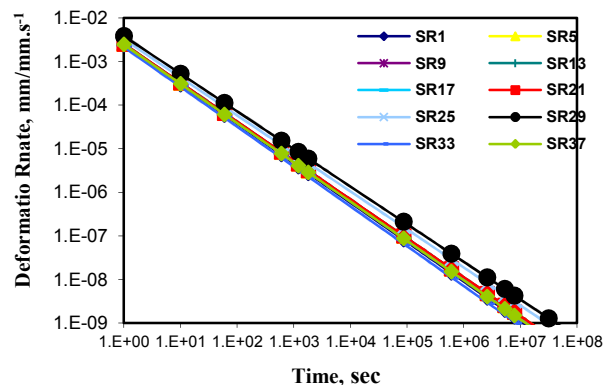


Figure 4. Variation of the sample's deformations rate of tube HDPE 80 with time.

It is important to note also that the deformation's rate decreases monotonically when the density decreases. Thus, the rate of deformation decreases when the density of binding

molecules increases. The most resistant to long term materials are those that have a dense network and the less deformable. Network density can be interpreted in terms of tangles and binding molecules that contribute to its strength and resistance to the deformation [4].

From the table 4 that gives the deformations' values of different samples of the gas tube, Crude oil and Toluene methanol are solvents that have a real impact on this resin and mark a very important value of the deformation in respect to other chemical environments. This latter has practically the same effect and the deformations' values recorded are lower compared to solvents. The obtained results show behavior consistent with gathered information in the literature for the polyethylene [3, 11, 16 and 12].

4. Conclusion

To ensure proper performance of Thermoplastics pipes over the required lifetime, durability analyses are needed to

Table 3. Values of the constants *A*, *B*, *C* and *n* obtained by treatment of the results of 18 months for each sample in different chemical environments.

Environment	Specimen	A	Exponent n	B	C	Coefficient of Determination	
						Power Model	Logarithmic model
1% HCL	SR1	0,0248	0,0958	0,0269	0,0031	0,9715	0,8227
10% HCL	SR5	0,0233	0,1085	0,0261	0,0034	0,98	0,8209
20% HCL	SR9	0,0239	0,1066	0,0268	0,0033	0,9808	0,8311
1%H ₂ SO ₄	SR13	0,0233	0,1075	0,026	0,0034	0,9766	0,8142
10%H ₂ SO ₄	SR17	0,0239	0,1021	0,0267	0,0031	0,9724	0,8311
20%H ₂ SO ₄	SR21	0,0235	0,1078	0,0263	0,0034	0,9791	0,8218
Crude oil	SR25	0,0253	0,1277	0,028	0,0053	0,9041	0,6833
Toluene methanol	SR29	0,0282	0,1364	0,0328	0,0061	0,9362	0,7572
Distilled water	SR33	0,0251	0,0858	0,0264	0,0029	0,9206	0,7637
Free air	SR37	0,0249	0,0986	0,0271	0,0033	0,9641	0,8088

Table 4. Samples Deformations of Tube HDPE 80 in %.

Nbr of specimen	SR1	SR5	SR9	SR13	SR17	SR21	SR25	SR29	SR33	SR37
Chemical environment	1% HCL	10% HCL	20% HCL	1% H ₂ SO ₄	10% H ₂ SO ₄	20% H ₂ SO ₄	Crude oil	Toluene méthanol	Distilled water	Free air
Deformation (%)	6,62	6,87	6,87	6,62	6,62	6,87	10,44	10,44	6,62	6,87

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adequately account for the effects of loading, time, temperature, environmental conditions, as well as the role of pipe defect and imperfections on relevant polymer properties and pipe performance.

In this work, we have determined the influence of chemical environments on the networks of HDPE transport and distribution of natural gas.

The results indicate that the mixture of toluene and methanol with the crude oil are the most absorbed by the HDPE and represent the most important values of the deformation and deterioration of the material properties.

The curves $\varepsilon = f(Ln(t))$ are characteristics of creep behavior, in short-term, of semi-crystalline visco-elastic materials. These changes in mechanical properties are consequences of crystallinity changes imposed by the manufacturing process.

Annex

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