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EXPERIMENTAL STUDY OF DUCTILE AND FRAGILE PIPE CRACKED IN HIGH-DENSITY POLYETHYLENE (HDPE)

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Absract. In this paper the experimental study of the fragility, ductility fracture and the mechanical behavior of high-density polyethylene pipe cracked is subject with know the damage law taken account of the deformation velocity which related to the cracking speed. The ductile fracture of HDPE pipes is characterized by a short crack that propagates rapidly perpendicular to the direction of stretching. The tests were carried out on different specimens cracked and uncracked taken from high density polyethylene (HDPE). The main aim of this study is studied the damage and material HDPE with two cases cracked and uncracked specimens of HDPE and knowing the physical quantities and the understanding of the effect of the deformation velocity on the mechanical behavior.

Keywords: density polyethylene (HDPE) pipes, ductile fracture, characteristics, damage, fragility, tensile test, crack, propagation

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1. Introduction

Drinking water distribution has taken a great evolution. It is carried out using pipes made of thermoplastic material, such as high density polyethylene (HDPE) [1-3]. The drinking water distribution over a long distance by HDPE tubes requires the knowledge of the distributed water flow and the conditions on the ground to ensure good distribution and avoid leakage faults (Fig. 1). Generally, these leaks are the cause of poor removal of drinking water from the pipes. In this context, scientific research becomes necessary to identify the mechanical behavior of the material (HDPE).

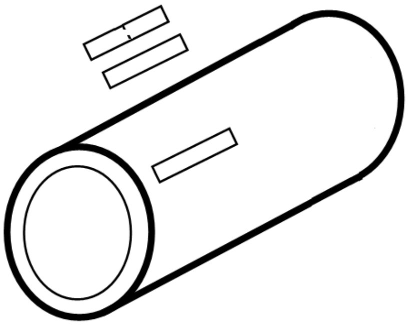

Fig. 1. Rotation sampling of the test tube

Many studies can be found in the literature on the subject of the brittle ductile in HDPE pipes [4,5]. Moreover, other researchers [6,7] investigated the crack and fracture properties of HDPE.

Mizera et al. [8] analysed the influence of process parameters change on mechanical properties of the surface layer of HDPE product, characterised by its hardness. Andreas Frank et al. [9] demonstrates the potential of the cyclic CRB test not only for a standardized quick material ranking by SCG resistance, but also for fracture mechanics based lifetime prediction of modern polyethylene (PE) pipe grades. [10] The Craze branching in thermoplastic material such as HDPE with an inhomogeneous microstructure may therefore increase the toughness. The interpenetration of molten chains leads to entanglement phenomenon, for any chain longer than a molar mass critical [11].

The dislocations which have been observed on monocrystals are mainly located in the crystallographic planes containing the chains [12,13].

The plastic zone is given by "stress whitening" which is caused by density fluctuations, probably due to crazing and voiding processes [14].

In thermoplastic material, Lee et al. [15] have shown experimentally that the increase in fracture toughness of many engineering polymers derives from the formation of multiple crazes at crack tips.

The study aim concerns the identification and the study of the behavior (fragile and ductile) of thermoplastic and high density polyethylene tubes cracked under internal pressure to obtain the true mechanical behavior in real working conditions and to solve the rupture problem which usually occurs at the wall outer surface.

Butler et al., Aboulfaraj et al. [16-19] have examined the microscopic structure and the plastic deformation processes of HDPE thin films.

2. Experimental work

In this study, in order to determine the behavior law of the two cracked and non-cracked structures, an experimental study based on mechanical tests under static loading is conducted. Series of tests are studied to characterize the material, followed by tests of mechanical analysis of the resistance of the different deformation rates.

3. Study material

The study material is a thermoplastic material with a complex viscoelastic-viscoplastic behavior and good corrosion resistance, called high density polyethylene (HDPE).

The used material was manufactured over time in the form of granules imported by the company STPM CHIALI located in Sidi Bel Abbes (ALGERIA) [20]. It was then extruded to make tubes of different diameters. The extrusion conditions are determined in order to guarantee the most homogeneous cooling possible. This material is designed to work at a pressure of 4 bars. The technical, physical and chemical specifications of the material are grouped in Table 1.

Table 1. Parameters and characteristics of HDPE

Density	930 kg/m^3
Molecular weight (*Mw*)	310,000 (g/mol)
Crystallinity rate (*Xc*)	74%
Fusion temperature (*Tf*)	203°C
Fluidity index	0.2–1; 4 g/10 (min)
Black carbon	2–2.5%

In this study, the tensile test pieces made of HDPE (Figure1) were taken from a tube with a diameter of 315 mm, 28.2 mm thick and 300 mm long. Two tests were carried for each case and for the same drawing speeds (*Ve* = 10 and 50 mm / min). The temperature of all tests was equal to ambient one (*Ta*≈ 23 °C).

Tensile Test. In this study, the experimental tensile tests are tests which enable the damaged tubes identification and classify the degradation of the used HDPE. In the literature, several works have confirmed the efficiency and the adequacy of the cracking technique for studying the ductility and brittleness of the tubes and have demonstrated that the use of tensile tests makes it possible to reproduce stresses close to reality.

To characterize the material mechanical behaviour and to study the damaged tube degradation, tensile tests are used on flat-shaped test pieces (Fig. 2).

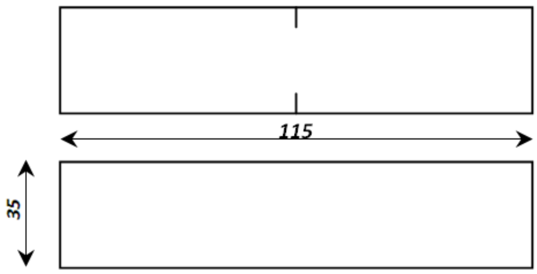

Fig. 2. Geometry of flat specimens (mm)

The tensile tests on this type of test piece were carried out using a servo-hydraulic fatigue machine of the INSTRON 8516 type with a capacity of 100 KN [21]. This machine makes it possible to impose uniaxial forces to measure the displacement of the machine jaws and the load applied at a maximum frequency of 50 Hz.

Cracking tests on flat test specimens were carried out at the Reactive Materials and Systems Laboratory (LMSR) of Sidi Bel Abbes University. To carry out the experimental tests, a longitudinal crack on the flat specimens was created and in this case, a double crack whose ratio a / t = 0.08 and a / t = 0.16 was chosen.

Hardness Test. The hardness measurement procedure on thermoplastic material is much simpler than other materials. The shore D hardness measurement gives us a first evaluation of the mechanical properties of the material. By this technique, we drew a straight line along the test surface. The hardness shore D tests specimens are prepared by cutting several slabs from the pipe in the longitudinal direction. The hardness shore D procedure is far simpler than the others.

The hardness shore D tests were carried out according to ASTM standard D2240-00 [22] by a shore D durometer set on a milling machine. The indenter is moved into the test material under a preliminary distance from 2.5 mm; this distance is set according to the ASTM standard D2240-00 (Fig. 3).

In this part, the hardness measurement at the top of a crack with $a / t = 0.08$ and $a / t = 0.16$ is generally defined as the resistance of a material. The hardness measurement gives us a first assessment of the mechanical properties. It is used to take the existence of the anelastic zone (ZB) which surrounds the plastic zone (ZA) at the end of the crack (Fig. 4).

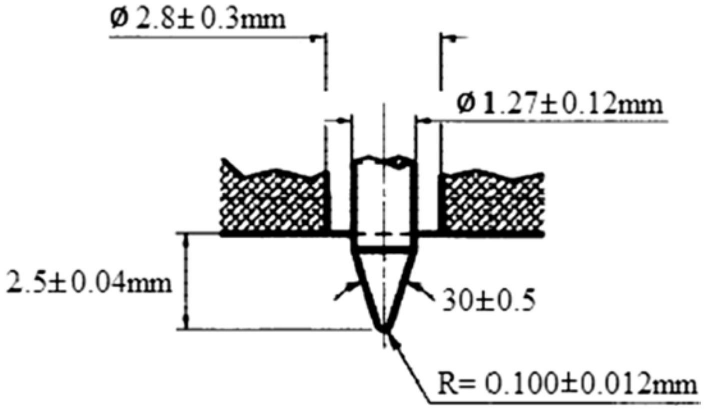

Fig. 3. Hardness shore D indentation and measurement

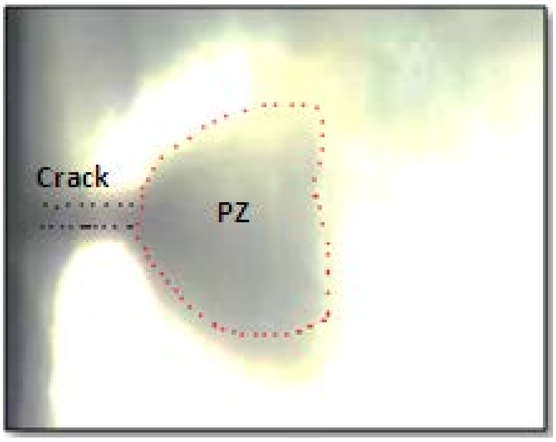

Fig. 4. Plastic zone (ZP) illustration at the crack end

4. Results and Discussion

Tensile test results. The obtained results from tensile tests for different strain rates are shown graphically in Fig. 5. It can be seen that the general shape of the stress-strain curves is characterized by four main areas: an elastic behaviour at low deformations following a plastic deformation then, a structural hardening due to the reorganization of the chains in the stress direction and finally a significant hardening before the final break.

It is also observed that there is a very significant drop in the elongation value at the break for a deformation speed of 50 mm / min. It is noted that there is a good correlation of the elastic part and that there is a material hardening of at the speed of 10 mm / min.

Also, the material is ductile at high stress for the movement speed of 10 mm / min and with a strain at break equal to 120 mm. For the movement speed of 50 mm / min, the material has a brittle character for which the lifetime is much less sensitive to stress since the deformation at break is of de 40 mm.

According to the stress strain curves (Fig. 6) for the cracked specimens, it can be seen that the study HDPE presents a significant increase in the flow stress with the strain rate, depending on the Young's modulus. HDPE exhibits fragile behaviour at high deformation rates.

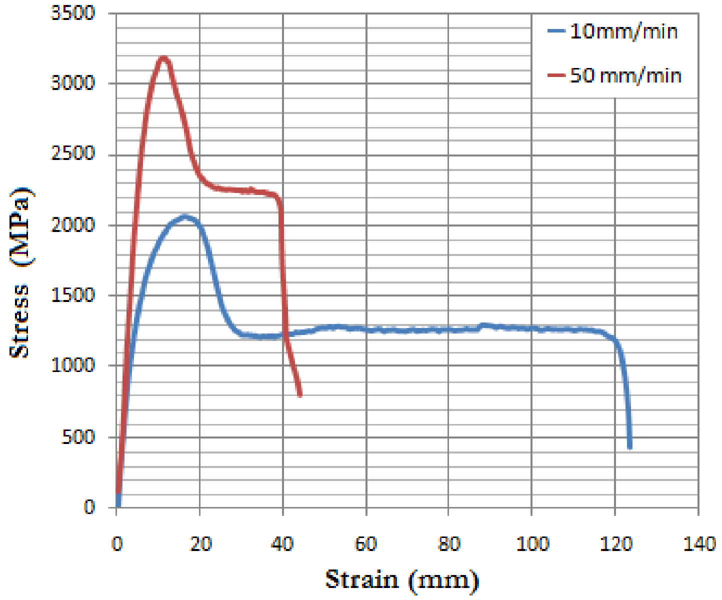

Fig. 5. Stress-Strain curve of test pieces without cracking

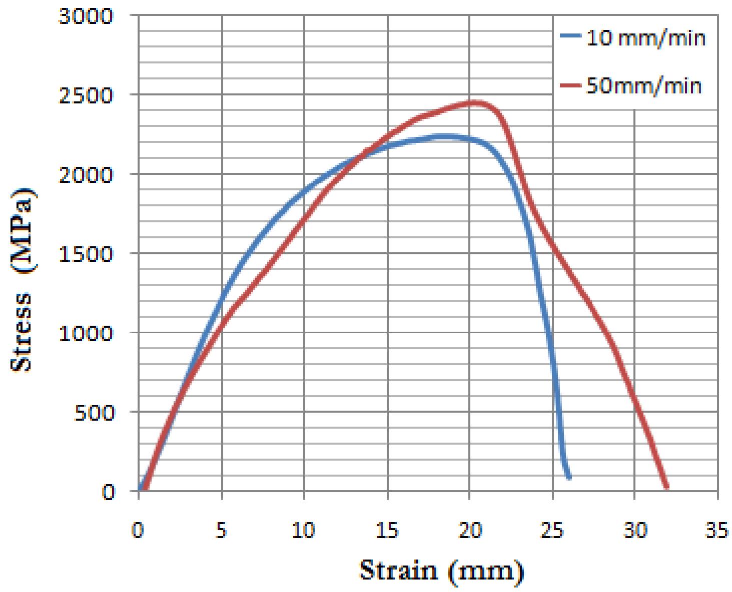

Fig. 6. Stress-Strain curve of test pieces with crack. (*a/t* =0.16).

The fragility revealed by a low elongation value at the break corresponds to the undulation of the internal wall of the tube between the zones.

In multiphase polymers, the value of Young's Modulus is generally lower than the matrix polymer if the second-phase particles are rubbery, but higher if rigid and well-bonded [23].

Figure 7 illustrates the deformation stages of the HDPE tensile test specimen, for no-crack, double-crack and post-break. A HDPE specimen is tested in a mechanical test bench. Figure 8 shows the deformation of the specimen during the test. A neck forms and then propagates through the parallel section of the sample. Then it moves to the supports and a second neck is in the parallel section is created. Eventually, the specimen breaks. Large deformation tensile test with HDPE specimen.

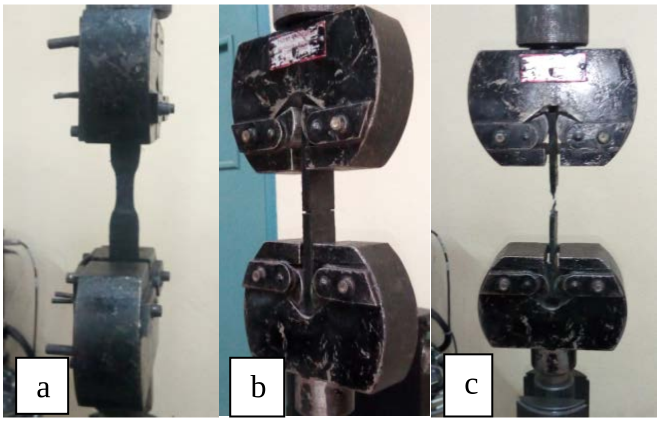

Fig. 7. Tensile specimens. a) Without crack; b) Double crack; c) After rupture

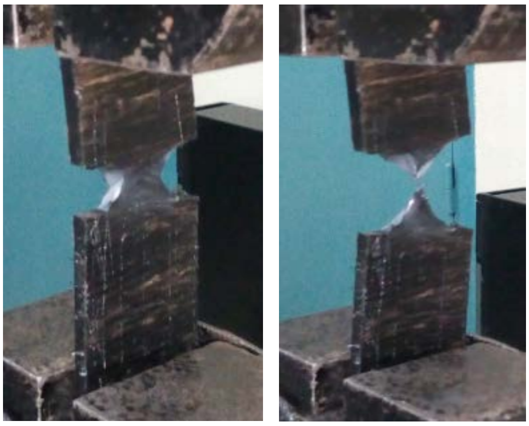

Fig. 8. Rotation Test pieces during the test

Hardness Test Results. The plastic zone (ZP) microstructure plays an important role in determining the mechanical properties. The mechanical properties of the polyethylene used depend on the crystallinity, density and morphology of the molecules. Figure 9 shows the illustration of the plastic zone (ZP) at the crack end. To see the influence of the hardness on the plastic zone (ZP), one measures the hardness for a value of radius (r = 0) of the crack end, with constant measurement steps (P) of 0.5 mm (Fig. 9).

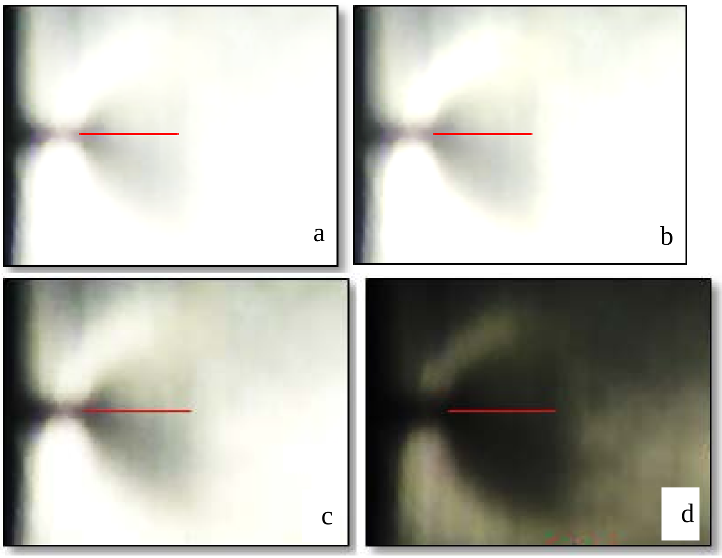

Fig. 9. Illustration of the plastic zone (ZP) at the end of the crack.
(a and b with a/t= 0.08), (c and d with a/t =0.16)

Table 2. Results of the hardness of the plastic zone (ZP). (*a/t* =0.16)

Step (mm)	0.50	1.00	1.50	2.00
Hardness (Sh D)	56.00	54.50	54.00	53.00

The hardness evolution for the different step values (P) is illustrated in Fig. 10. For a short crack a / t = 0.08, the hardness presence in the plastic zone leads to a small increase in the stress intensity factor compared to a short crack a / t = 0.16. This increase is the result of the stress concentration in the notch where the crack begins.

In addition, the stress intensity factor also decreases with the crack advancement according to the test piece thickness.

It can be seen that the stress concentration in the plastic zone has a significant impact. The change in material properties in the plastic zone is mainly caused by changes in crystallinity.

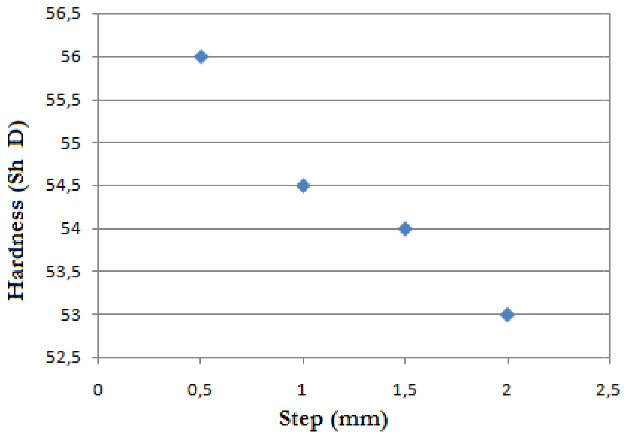

Fig. 10. Illustration of the hardness evolution for the different step values (P)

5. Conclusion

The work carried out in this study aims to first know the mechanical behaviour of the damaged pipe. This kind of pipes is widely used in an industrial sector in Algeria for different working conditions and to perform numerical simulation. Thus, complete mechanical, thermal and structural analyses were carried out with regard to thermal phenomena occurring during and after the process.

Thus, complete mechanical analyses were carried out with regard to cracking phenomena and to understand the mechanisms which intervene during cracking and the relationships which exist between the microstructure (hardness) and the mechanical properties in the plastic zone, a set of mechanical tests were carried out on HDPE tubes.

The results presented experimentally allowconcluding that the deformation and cracking mechanisms are mainly governed by the different deformation rates.

1. The study material presents a good behaviour for a low strain rate. This made it possible to obtain consolidated materials having good mechanical properties due to the stress intensity factor.

2. The hardness in the plastic zone (ZP) increases as a function of the enlargement of the plasticity zone.

The ductile and fragile behaviour of a material reflects the degree of plastic deformation it is capable of suffering before its final fracture.

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