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Study of the mechanical fracture behavior of rigid PVC pipes buried supply of drinking water: Experimental application for SENT specimens

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ABSTRACT

For several years, we are seeing significant growth in the production of polymers, which currently equal in volume than steel. On the other hand, the use of polymers is becoming more diversified.

The work we present is interested in mechanical fracture behavior of rigid PVC pipes. Initially, we selected standardized dumbbell specimens for determining mechanical properties, then we manufactured rectangular specimens of different lengths notched (SENT), thin to track damage mechanisms and the phenomenon Laminating the nick of this material background. During charging, it is observed that the plastic deformation occurs while the slow uncracked ligament. This plastic deformation is often accompanied by blunting and a strong stretching of the material in the immediate vicinity of the tip of the notch which is manifested by color change of the material in this area.

Photographic observations of the specimens tested , indicate the sequence of successive events the following mechanisms: a separation of the lips of the mechanical notch , followed by the initiation of the crack in a highly stretched area (white area) , this characteristic laundering PVC material to stretch the material of the highly damaged area around the mechanical notch.

Keywords *- polymers, mechanical fracture, notch, rigid PVC, SENT.*

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I. INTRODUCTION

Plastic materials occupy a large part of the drinking water supply pipelines because of their ease of installation and relatively low production costs. However, recent statistics indicate that losses in drinking water systems averaging 35%.

These water losses concern many municipalities and governments, spending on repairs and replacing defective pipes are very expensive.

In a country like Morocco **[1],** where the rainy seasons are short and are becoming increasingly rare. The drinking water supply of cities and villages is almost 100% by pipeline. This water must be handled by Simony and should not be wasted.

In most of cases, the material is often implicated **[2].**

Our study focuses on rigid PVC pipes. Indeed, during installation in housing pipes these pipes are often subject to accidental impacts such as falling pebbles, bad manipulation of the conducted by Hammer construction equipment, etc ... It becomes important for engineers to appreciate their capacity to withstand the brutal crack propagation. In most cases, the material is often implicated [2].

Our study focuses on rigid PVC pipes. Indeed, during installation in housing tubes, these pipes are often subject to accidental impacts by poor handling such as falling rocks, hammers, construction tools etc. ... It becomes important for engineers to assess their ability to withstand the brutal crack propagation.

In this paper we investigated the mechanical degradation which involving precracks specimens rigid PVC, applying a system of forces and submitting his crack to the opening mode (mode I).

This article provides an update on a study of the mechanical degradation, involving pre-crack specimens rigid PVC, applying a system of forces and submitting her to a crack open mode (mode I).

After achieving several static testing of samples rigid PVC, force-displacement results allowed us to know the mechanical fracture behavior of rigid PVC samples in order deepen benefit our knowledge about the material, we sought to characterize the vis-à-vis its resistance to crack propagation, we sought to characterize it towards its resistance to crack propagation.

It's the mode by opening the lips of the crack (mode I) that has retained our attention. so the samples used for this work are SENT specimens (Single Edge Notched Tension.

II. MATERIALS AND METHODS

II.1. Specimens and testing devices:

The flat specimens used are from a pipe with the pipe dimensions: diameter 90 mm and thickness 4.6mm Figure.1. They consist essentially of PVC (rigid PVC) gray in color and come from the same casting.

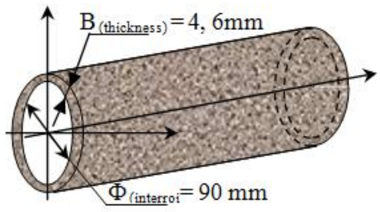

***Figure 1**: schema of a rigid PVC pipe*

From sections of tubes (figure 1),we cut at first bands which we shall be of use afterward to the preparation of our specimens by means of a jigsaw.

Next, we introduced them in an oven at a temperature between 125 and 130°C in order to facilitate the extraction of the samples:

The first are dumbbells according to ISO 527-2, Figure 2, Table 1 and the second are rectangular according to standard ISO13576.

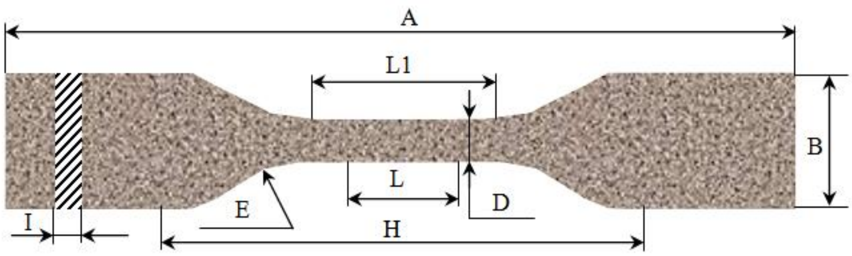

***Figure 2**: Geometry of the test specimen for the tensile test*

Table 1**: dimensions of the dumbbell specimen for the tensile test **[3]

Symbole	description	Dimensions (mm)
A	Minimum total length	115
B	Width at the ends	25±1
L1	Length of the calibrated portion	33 ±2
D	Width of the parallel length	6 ±0.4
E	Small bending radius	14 ±1
L	Gauge length	25 ± 1
H	Initial distance between jaws	80 ±5
I	thickness	4,6

The flat specimens are intended for measuring the toughness of rigid PVC material, the test specimen thus obtained were cut according to standard the Figure.3 and Table 2 show the dimensions of the studied specimens with different length Notch such that: $0.2 \leq a / W \leq 0.6$,: with L; the length of the specimen, B; thickness, W; and the width; the length of notch.

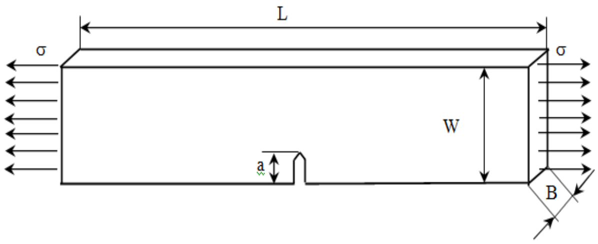

***Figure 3**: Geometry of the specimens SENT*

Table 2**: SENT specimen dimensions for the failure test **[4]

Symbole	description	Dimensions (mm)
L	Length of the specimen	100
W	Width of the specimen	10
B	specimen thickness	4,5
a	Interval of the notch length	$2 \leq a \leq 6$

In the case of ductile polymers for which significant plastic deformation is observed, it is necessary to use a geometry wherein the stress gradient is important, First, in table.3,we take a dumbbell configuration in order to determine the mechanical properties, in table 2. The specimens SENT (Single Edge Notched Tension).
in order to determine the process of internal and external fracture the vicinity of the crack tip, with different lengths notches such that:
$0.2 \leq a / W \leq 0.6$,: with a is the length notch and W is the width specimen.

Table 3: Mechanical properties of a rigid PVC pipe

properties	values
Modulus of elasticity	2700 -3000 MPa
Tensile breaking stress	45 MPa
Elongation at break in tensile	100 %
Compressive strength out	50 – 70 MPa

III. RESULTS AND DISCUSSION

III.1. Curves force / displacement:

Table 4 corresponds to the recording of load / displacement on specimens SENT (Single Edge Notched Tension) of different lengths notches, for this work, we have engaged ten specimens (a = 2, 3, 4.5 and 6 mm) for each notch length, we conducted two mechanical tests, before each test we used a razor blade to increase the severity of the crack. Results shown are realized with a sensibility of 0.006.

Table 4: a summary of fracture test SENT specimens

Notch Length (mm)	Specimen number	Corresponding maximum force (KN)	Average maximum force (KN)
a = 2mm	1	1.25	1.11
	2	1.18	
a = 3mm	1	1.14	1.08
	2	0.97	
a = 4mm	1	0.92	1.21
	2	0.76	
a = 5mm	1	0.75	1.31
	2	0.78	
a = 6mm	1	0.66	1.14
	2	0,57	

Figure 4 shows the change in load / displacement of three different lengths notches, we note that the results obtained on notched specimens then are primed the same evolution for different lengths notches, we also note that the importance of the ductility of the material gives it a nonlinear behavior. The change in the load depending on the notch length is shown in Figure 5.

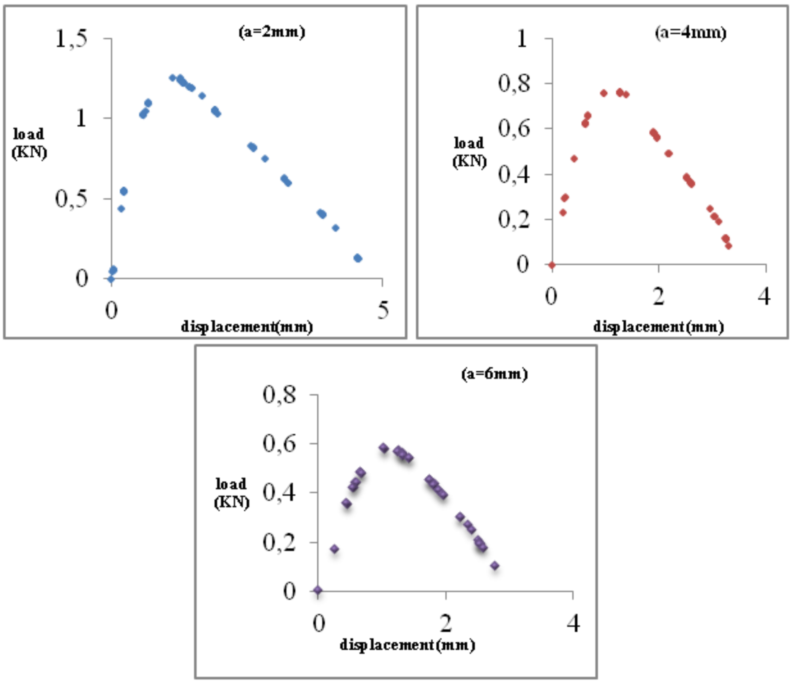

Figure 4: *Evolution of force/displacement of the different length notch:a) a = 2mm, b) a = 4mm, c) a = 6mm*

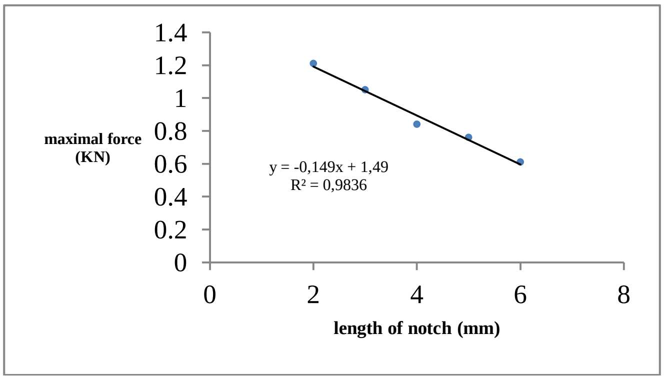

Figure 5: *Evolution of the maximal force according to the length of notch*

Figure 6 shows the overall results, the course of the five curves load / displacement. During charging a linear part is observed then continued away from the real curve to the right ideal load-displacement. This nonlinearity is mainly due to a strong plastic deformation at the crack tip **[5],** a possible slow crack propagation **[6]** and the fact that the crack tends to spread roughly by blows of very low intensity.

The maximum load is obtained with the same movement of the lips of the mechanical notch. This charge is higher as the length of the cut is small. The crack propagation occurs in a highly-damaged area lamination. The size of the damaged area is more important than the length of the cut is small.

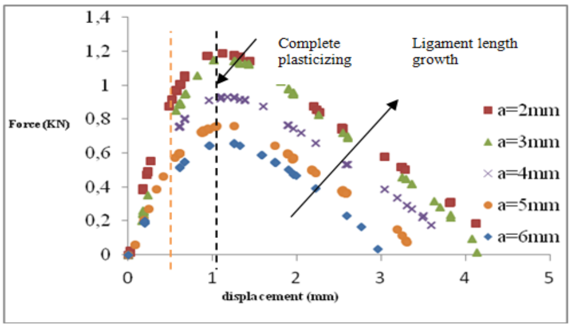

Figure 6*: strength evolution as a function of displacement of different lengths notch*

The shape of the curves in Figure 6, confirms once again the high ductility of rigid PVC material with a priori lamination of all non-cracked but heavily damaged ligament.

III.2 Mechanisms of the crack spacing of the lips and the final rupture:

The rupture mechanism occurs according to the scheme of Figure 7. During charging generalized plastic deformation occurs while the slow uncracked ligament. This deformation, accompanied by a constriction in the lower strength section. The final rupture is represented by the shaded area according to the diagram in Figure 7.

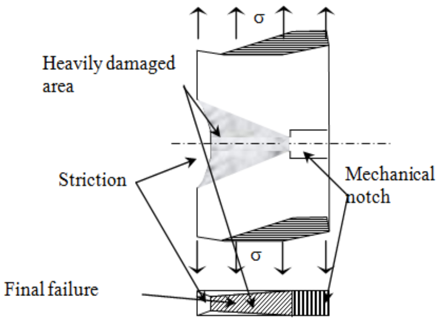

Figure 7*: Schematic representation of the final rupture mechanism*

The spacing mechanism lips of the cut occur according to the diagram in Figure 8. During charging, the generalized plastic deformation occurs while the slow uncracked ligament. This deformation is accompanied by a constriction in the lower resistance of section, causes a significant separation of the lips of the mechanical notch. The mechanism of the separation of the lips of the fissure and the strong deformation is represented by the diagram of Figure 8.

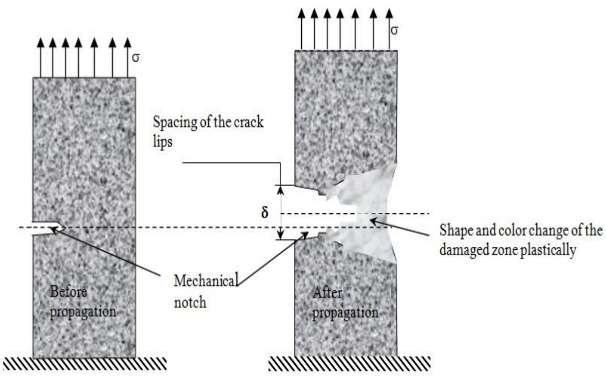

Figure 8*: Schematic representation of the separation mechanism of the fissure lips*

Observation of photos, 9 specimens during the test indicates the sequence of successive events of the mechanisms mentioned above that is to say the spacing of the crack and the final fracture.
(a) Initiation of the opening of the fissure in the initial end of the notch;
(b) Formation of the area at the end of the crack (the white area);
(c) The complete plasticization of the length of the ligament;
(d) And finally the entire damage of the specimen tested.

Figure 9: *successive events during testing; a) initiation of the opening of the fissure in the initial end of the notch; b) formation of the area at the end of the crack (the white area); c) the complete plasticization of the ligament length, d) the entire damage of the specimen tested*

We observe the photographs in Figure 10, Form macroscopically white damaged area that represents a fiber observed microscopically.

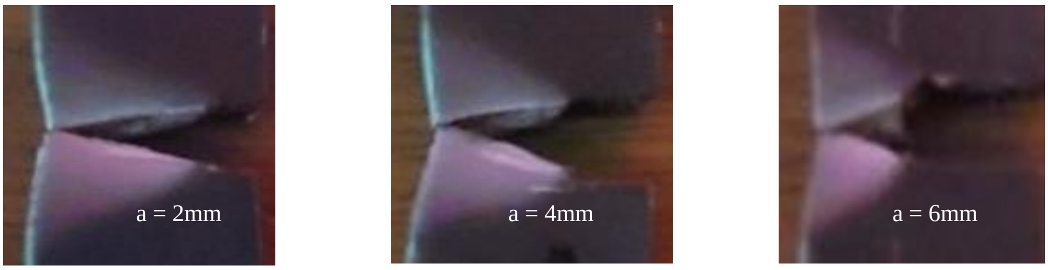

Figure 10: *Form of the damaged zone*

Photographs of Figure 10, is also observed a strong bleaching the failure to turn. This bleaching characteristic of stretched material locates the macroscopic damage phenomena occurring on a microscopic scale [7], [8].

Relatively recent studies have confirmed that bleaching was strongly related to the microscopic damage of the material at a microscopic analysis of fancies to the breakdown of rigid PVC samples subjected to a tensile test, found that bleaching was connected two distinct phenomena:

1. The formation of cracks in the pinch zone;
2. Cavities of training on the fracture surface (for crystalline polymers).

In summary, we looked at in this part of the influence of some factors on the damage of the material, in fact, the notch effect and ductility index that we will deal with in the next paragraph, play a role in embrittlement of the material studied.

III.3 ductility index:

The materials used in this work are also amorphous polymer type as PP, rigid PVC. In this work, the authors [7] described five possible cases introduce an indicator called "ductility index".

$$D_L = \frac{d_r}{l}$$

Or D_L is "ductility index" r is the displacement at break and l is the length of the ligament.
Different cases are discussed according to DL:
• (a) Fragile (DL <0.1): Very fast unstable crack propagation is established before the lamination of the ligament.
• (b) ductile instability (0.1 <DL <0.15): This case is characterized by a small plastic deformation with a slight bleaching near the notch. However, despite the plasticization in the fracture process zone, unstable crack propagation leads to a brittle behavior.
• (c) blunting ("blunting") (1 <DL <1.5): in this case, the process of breaking zone is fully plasticized before the crack propagation. After lamination, the end of the crack.
• (d) Striction ("necking") (DL> 1.5): No crack propagation appears in the section of plastic ligament, which continues to deform plastically and to act as a tensile test and form a constriction.
• (e) Stable propagation after the yield point ("Post-yielding") (0.15 <DL <1), the crack begins to spread stably after complete lamination of the ligament. strongly blunted and this prevents crack propagation.
By applying équation.1, LD values of all the materials used in this study are summarized in Table 3.

Table 5: *ductility index D_L*

Notch Length (mm)	**ligament Length (mm)**	**D_L ductility index**	**cases**
2	8	0.523	"Post-yielding"
3	7	0.545	"Post-yielding"
4	6	0.561	"Post-yielding"
5	5	0.659	"Post-yielding"
6	4	0.67	"Post-yielding"

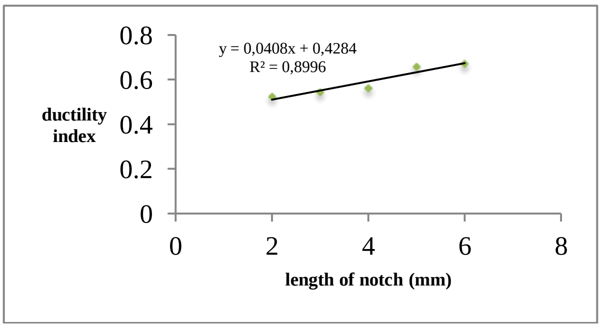

Figure 11*: Evolution of the ductility index as a function of the length of notch*

Figures 11, give results commensurate with the literature, the index of ductility increases with increase created defect (notch), which means that the necking zone widens the bottom of notch (fault localization) more the material is more ductile it is strictionné (Figure 11).

The shape of the damaged area to the time of initiating the propagation of a crack, shown in Fig. 12, was obtained by photography, it is observed that the ligament is completely plastic and cracks propagate after complete lamination. Finally, samples of rigid PVC rather correspond to the case where the spread is stable after the stress threshold (event e).

More generally, during testing it has been shown on the rigid PVC material that increasing the length of notch reduces the forces applied to the test with the reduction of the test time to rupture.

Table 6 shows the test development time for each type of test to failure.

Table 6*: Evolution of testing time until failure depending on the length of notch*

Notch Length a (mm)	number test	testing time (s)	Average test time (s)
2mm	1	292	285
	2	278	
3mm	1	316	284.45
	2	252.9	
4mm	1	265.33	247.66
	2	230	
5mm	1	277	250.5
	2	224.01	
6mm	1	212.63	222.3
	2	232	

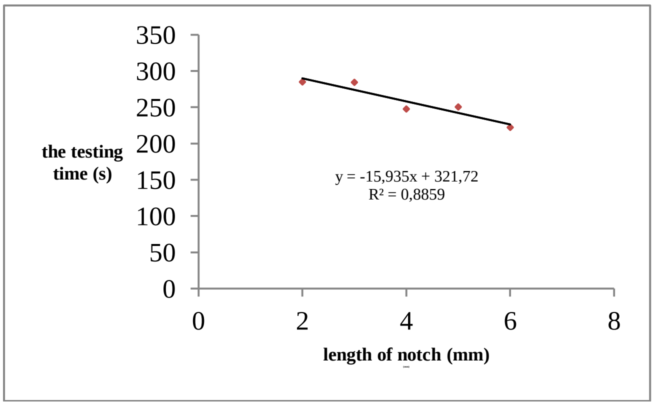

Figure 12: *Evolution of the ligament length depending breaking time*

The spacing mechanism lip of the cut occurs according to the diagram in Figure 10. During loading, the generalized plastic deformation occurs while the slow uncracked ligament. This deformation, accompanied by a constriction in the lower strength section, causes a significant separation of the lips of the mechanical notch. The spacing mechanism lips of the fissure and of the strong deformation are represented by the diagram of Figure 10.

IV. CONCLUSION

Our study shows that the crack propagation occurs in an area heavily damaged by widespread lamination while the slow uncracked ligament. The size of the damaged area is more important than the length of the cut is small. Ce travail consiste dans un premier temps à l'élaboration d'une méthodologie Expérimentale qui concerne la détermination du comportement à la rupture des éprouvettes SENT de différentes longueur d'entaille effectuée dans des conduites en PVC rigide, soumises a une sollicitation statique en mode I.Following the progressive evolution of the crack, in a second step we are interested in the behavior of the bulk polymer as a whole: from small deformations until the plastic flow, softening and hardening. From the tests carried out we observed for each assay that priming is preceded by extensive plastic deformation. The spacing mechanism lips of the notch occur in the direction of the applied load, such movement is more than the size of the crack is small. This separation of the lips is accompanied by a strong constriction in the section of least resistance. The observation photographs of specimens tested, indicates the sequence of successive events of the following mechanisms, during the spreading of the crack to the crack: the crack initiation in a highly stretched area (white area), full of plasticization uncracked ligament and finally steady crack propagation after the plastic flow threshold in a very dull area

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