STRAIN RATE SENSITIVITY OF THE ESSENTIAL WORK OF FRACTURE METHOD APPLIED IN POLYMERS

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Abstract: The resistance in service of polyethylene plastic pipes is normally evaluated by the internal hydrostatic pressure of long duration. The aim of this study is to evaluate the strain rate sensitivity of the Essential Work of Fracture (EWF) in polyethylene in order to analyze the material resistance to the slow cracks growth. Tensile tests were performed using sixteen polyethylene DENT-type samples at three different strain rates. By linear regression analysis, the values for the essential work of fracture (w_e) and the energy dissipation factor (Bw_p) were obtained. These results suggest that the slow strain rate sensitivity of the EWF method influence the crack propagation resistance.

Keywords: fracture mechanism, strain rate sensitivity, polymers.

1. INTRODUCTION

Polyethylene pipes are susceptible to unexpected creep failure in service, which result in an extensive water waste and increase its maintenance costs. These premature failures occur due to the slow crack growth [1].

Usually the long-term hydrostatic strength test is used to predict the pipes life through "regression curves", where the pipes are subjected to different temperatures and internal hydrostatic pressures for long periods. However, this test is very expensive, long and limited, since it do not provide enough information about the crack growth mechanism during the service life [2, 3].

On the other hand, the EWF method suggests that the energy necessary to occur the fracture of an elastoplastic material can be divided into two component parts. The first one is related to the material property. The second is governed by the ligament and geometry of the sample. During the crack propagation, the dissipated fracture work in the generalized plastic zone is not directly associated with the essential fracture process. Only the work absorbed within the fracture process zone is considered as a material property. Thus, the region at the crack tip is subdivided into two regions: known as the “end region”, where the fracture process occurs, and the “outer region”, where there is some voluminous ductility [4, 5].

Therefore, it is necessary a different approach to understand the mechanisms that may lead to early failures with the real factors that act on PE pipes during service. This study proposes a preliminary investigation about the validation of short-term test method for the quality control of polyethylene pipes via EWF.

2. EXPERIMENTAL PROCEDURE

The material used in this study was received in the form of pellets and the samples were made through compression molding at 190 ºC, according to ASTM D 4703-03. The samples were extracted from the compressed plate with dimensions of 38 mm width, 80 mm length and 0.2 mm thickness and then polished.

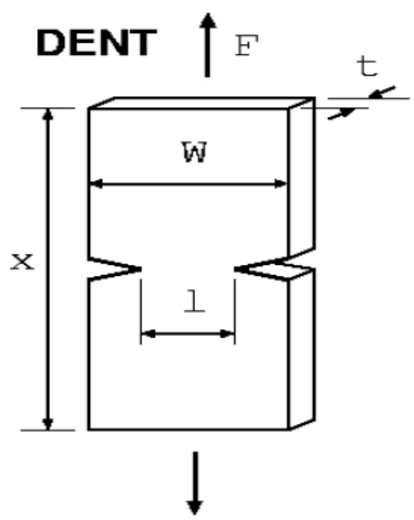

Figure 1 – Sample of DENT type.

The notchs were produced with a saw and the pre-cracks of 2 mm were introduced using a stiletto and hammer. Figure 1 shows the geometry of DENT (double edge notched tensile) type test used in the EWF method.

Figure 2 shows the pre-crack format obtained by stereoscope. Despite the rough method of pre-crack introduction, a good quality of the pre-crack was obtained.

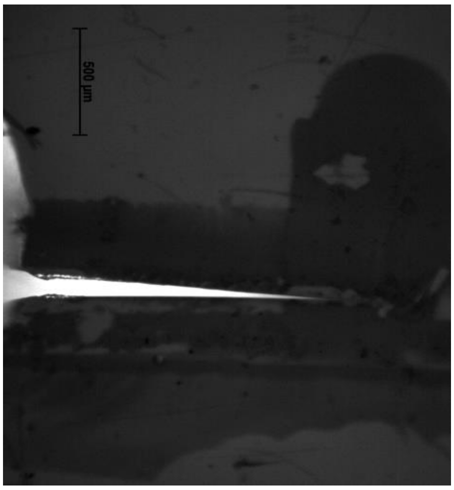

Figure 2 – Pre-crack introduced in the samples.

The samples were tensile tested in a universal machine. Sixteen samples with five classes of ligaments were produced, corresponding to the dimension "l" exhibited in Figure 1. Table 1 shows the ligaments, effective thickness and strain rate of each sample.

Table 1. Samples dimensions and strain rate tensile test.

Samples	Ligament (mm)	Thickness (mm)	Strain rate (mm/s)
1	8.1	1.77	10
2	5.7	1.71	10
3	12.1	2.05	10
4	12.9	1.94	10
5	10.4	1.81	10
6	5.0	2.06	1
7	9.0	1.98	1
8	13.6	1.88	1
9	10.65	2.15	1
10	12.4	2.12	1
11	12.2	1.94	1
12	14.4	1.87	0.1
13	7.0	1.96	0.1
14	7.75	1.98	0.1
15	10.1	2.00	0.1
16	11.4	1.93	0.1

3. RESULTS AND DISCUSSION

All the samples were tensile tested to the rupture. Figures 3, 4 and 5 show the graphs representing the samples with different ligaments submitted to a tensile test at strain rate of 10 mm/s, 1 mm/s and 0.1 mm/s, respectively. The similarity of the curves is a requirement of the EWF method.

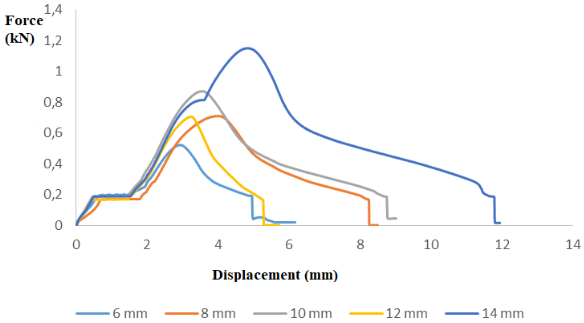

Figure 3 - Displacement curves versus the ligament of the samples tested at a strain rate of 10 mm/s.

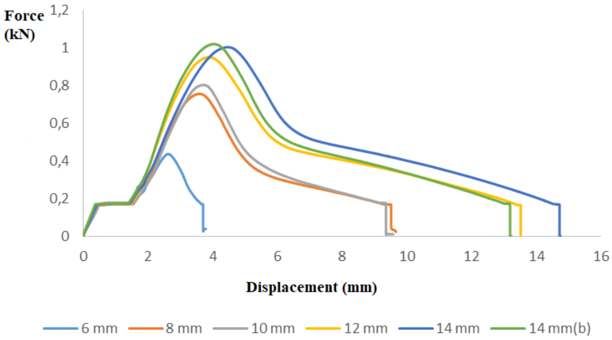

Figure 4 - Displacement curves versus the ligament of the samples tested at a strain rate of 1 mm/s.

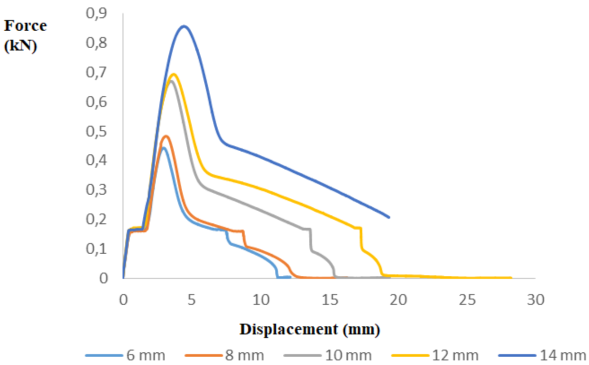

Figure 5 - Displacement curves versus the ligament of the samples tested at a strain rate of 0.1 mm/s.

The Total Fracture Work (W_f) was calculated from the area below the curves of Figures 3, 4 and 5. The Specific Work of Fracture (w_f) was obtained through the division of W_f for the thickness "t" and the ligament length "1". Thus, plotting the Specific Work of Fracture (w_f) versus the ligament (l), it is possible to obtain the Essential Work of Fracture (w_e) via the intersection of the curve with the y-axis. The Plastic Working Dissipation Factor (b_{wp}) can be obtained through the slope of the curve by a linear regression analysis, as can be seen in Figures 6, 7 and 8.

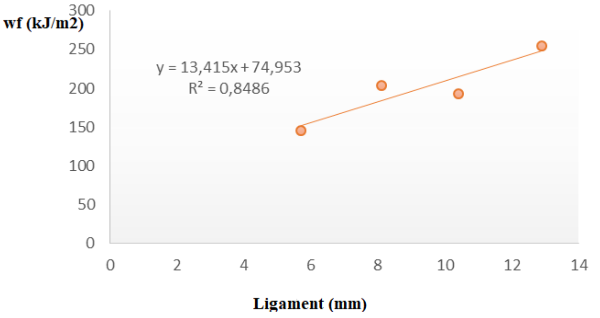

Figure 6 – Essential Work of Fracture versus the ligament of the samples tested at a strain rate of 10 mm/s.

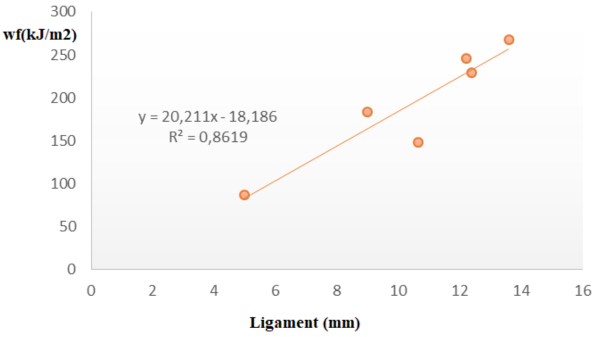

Figure 7 – Essential Work of Fracture versus the ligament of the samples tested at a strain rate of 1 mm/s.

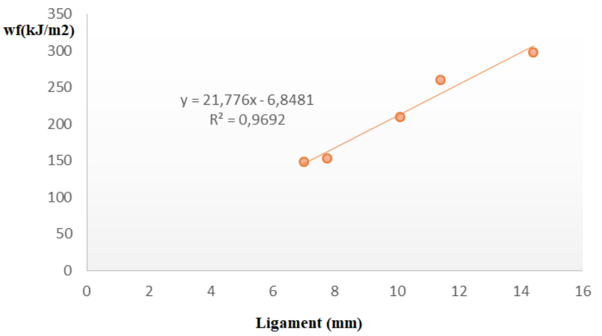

Figure 8 – Essential Work of Fracture versus the ligament of the samples tested at a strain rate of 0.1 mm/s.

Using EWF method is possible to analyze the resistance of the material to the slow crack growth. In the component referring to the "Essential Work of Fracture", which probably encompasses the "crazing process" and in the "Non-essential Work" component there is plastic deformation, which is a region susceptible to ductile-brittle transition [3].

These results suggest that the Essential Work of Fracture is very sensitive to the strain rate during tensile test. It is possible to observe that using lower strain rate of the tensile test, the Essential Work of Fracture (w_e) significantly reduces. However, it is verified that the energy dissipation factor (B_{wp}) practically does not change as a function of the strain rate.

The increase of the Essential Work of Fracture promote the increasing of the energy necessary to the cracks growth. Therefore, it is suggested that at higher strain rate during tensile tests the material resistance to crack propagation is higher, i.e. the material exhibit higher toughness.

The results obtained in this study indicate that the materials strength is influenced by the strain rate, which is typical of polymeric materials [6] also using EWF method is possible to investigate the material strength to the cracks propagation and performer a complete, low cost and fast test to evaluate the polymer quality in service.

Moreover, the Essential Work of Fracture values at the strain rate of 0.1 mm/s and 1.0 mm/s are negative, which is unexpected and unlikely. This may be associated with the need of a greater statistical significance. Typically, there is great dispersion in the results of the EWF method [7], which evidently affect the linear regression analysis by least squares method.

However, despite this, the results indisputably suggest the dependence between the crack propagation resistances with the strain rate during tensile tests.

4. CONCLUSIONS

The results suggest the sensitivity of the Essential Work of Fracture to the strain rate. This method shows promising for analyze the material resistance to the slow crack growth. The data obtained stimulate the development of new works aimed the application of the EWF method to evaluate the life in service of other polymeric materials.

5. REFERENCES

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