Research Inventy: International Journal of Engineering And Science
Vol.7, Issue 1 (January 2017), PP -17-21
Issn (e): 2278-4721, Issn (p):2319-6483, www.researchinventy.com

Evaluation of Damage by the Reliability of the Traction Test on Polymer Test Pieces

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Abstract: *In recent decades, polymers have undergone a remarkable historical development and their use has been greatly imposed by gradually dethroning most of the secular materials. These polymer materials have always distinguished themselves by their simple shaping and inexpensive price, their versatility, lightness, and chemical stability but despite their massive use in everyday life as well as in advanced technologies. Generally, these materials still not understood which requires a thorough knowledge of their chemical, physical, rheological and mechanical properties. This paper, we study the mechanical behavior of an amorphous polymer: Acrylonitrile Butadiene Styrene "ABS" by means of uniaxial tensile testing on pierced test pieces with different notch lengths ranging between 1 to 14mm.The proposed approach consists in analyzing the evolution of the global geometry of the obtained strain curves by taking into account the zones and characteristic points of these curves as well as the effect of the damage on the mechanical behavior of the polymer ABS, in order to visualize the evolution of the damage by a static model.*
Keywords: *Acrylonitrile Butadiene Styrene ABS, damage, Polymer test pieces, sudden rupture, tensile testing.*

I. Introduction

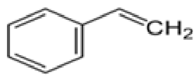
Amorphous polymers require a great interest cause of their plenty industrial applications. That interest reflected in many works on their mechanical responses [1].Acrylonitrile Butadiene Styrene (ABS) is one of these polymers which undergone a significant industrial development. Among these polymers, Acrylonitrile Butadiene Styrene (ABS) which has an undergone considerable industrial development, due to its properties (i.e. good heat resistance, high impact resistance and rigidity, dimensional stability and its decoration ability) [2]. The combination of three monomers which constitute of a chemical nature and of different physical properties makes it possible to have a material of interest with superior performance [3].ABS is the preferred material for rapid prototyping, molded parts for manufacturing home appliances, toys, automotive parts and computer hardware. Rapid prototyping integrates three essential concepts: time, cost and complexity of shapes [4].Nevertheless, our work consists in studying the mechanical behavior of the ABS subjected to a uniaxial loading such as tensile, in the first stage we carried out an experimental study to analyze the evolution of the overall geometry of the stress-strain curves of the ABS pierced test pieces and simply notched.In the second step, we have modeled the damage and the rupture behavior of the chosen material and we had followed the evolution of damage by the mathematical relation damage-reliability.

II. Experimentation

In this experimental part, we describe the chosen polymer (ABS), the morphology of the test pieces and the experimental techniques allowing the measurement of the stresses-deformations during the mechanical stress.

2.1 The chosen material: Acrylonitrile Butadiene Styrene

The polymer used in this study is Acrylonitrile Butadiene Styrene (ABS), it is an amorphous polymer produced by emulsion or bulk polymerization of acrylonitrile and styrene in the presence of polybutadiene.

Acrylonitrile 	**Butadiene** 	**Styrene** 
Ensures the stiffness and the thermal resistance	Makes the product harder and more elastic even at low temperatures	Gives to the ABS a good transformability

ABS is generally defined by three main properties: impact resistance, hardness and heat resistance.

Table 1: Characteristics of the ABS material

ABS Polymer	Type	T_g (°C)	Mold temperature (°C)	Thermoforming range (°C)	Linear shrinkage rate (%)
Acrylonitrile Butadiene Styrene	Amorphous	90-120	82	130-180	0,3 à 0,8

2.2 Operational method
The experiment consists in subjecting drilled test pieces with a hole of diameter Ø = 3mm and simply notched in ABS with different length of notches to static tests of traction cut according to standard ASTM D882-02 [5].

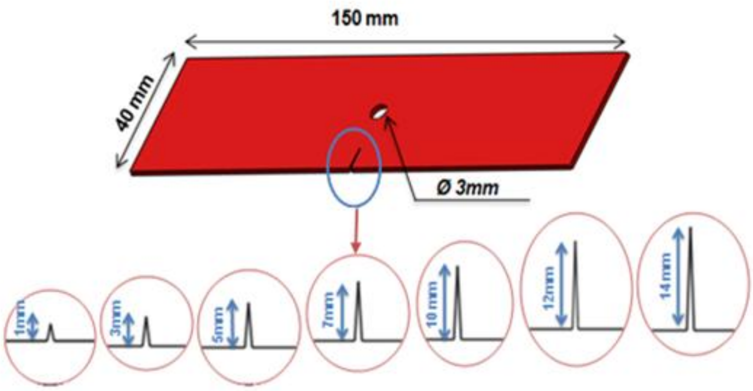


Fig 1: pierced ABS test piece of 3mm diameter prepared according to ASTM D5766M [6]

2.3 Experimental apparatus
The tensile testing of ABS are carried out on a universal tensile machine “Zwick Roell” with a maximum load capacity of 2.5 KN (figure 2), which allowed us to obtain a higher precision in our testing, given the nature of the test material, and the geometry of the test pieces which have a small thickness. The tests were performed at a uniform speed of 1 mm / min with a controlled movement.

Fig 2: universal tensile machine “Zwick Roell”

III. Result and discussion

3.1 The lifetime according to the notch
The following curves (figure 3) are showing the variation of stresses as a function of the deformations for the perforated ABS test pieces of 3mm diameter, with different notch lengths ranging from 1 to 14 mm.

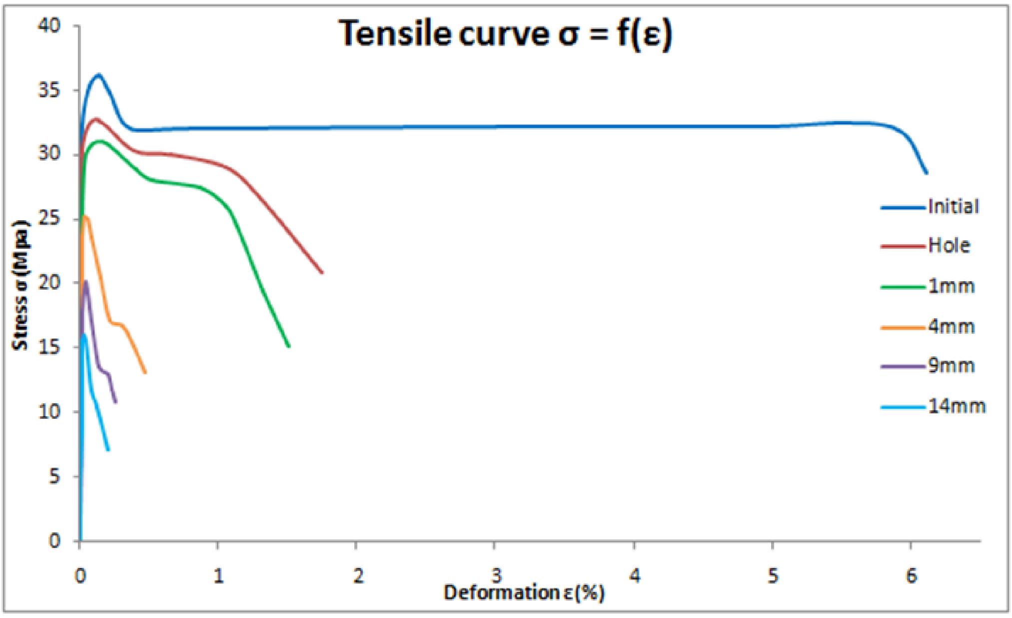


Fig 3: Tensile stress-strain curve of notched test pieces

The evolution of the curve gives an increasing and then decreasing appearance with an apparent discrepancy between the different values as a function of the length of the notch. By comparing the results of the blank versus damaged curves, we have a decrease in viscoelasticity when the notch length increases. These results show that the material stress increases (the size of defects increase), the viscoelasticity decreases and the material tends to become fragile.

3.2 Determination of damage - reliability

The static damage model consists in determining the evolution of the ultimate residual stress, the variations of which are essentially due to damage.Residual stresses are usually defined [7], as being the internal forces which remain in the mechanical parts when the latter are not subjected to any external stress. During the test, we followed the phenomenon of damage between the initial state and the complete rupture of the test piece, by measuring residual ultimate stresses, this phenomenon is quantified by the damage parameter according to the following equation [8].

$$D = \frac{1 - \frac{\sigma_{ur}}{\sigma_u}}{1 - \frac{\sigma_a}{\sigma_u}} \qquad (1)$$

With:

σ_u: Value of the ultimate stress in the undamaged initial state.

σ_{ur}: The value of the residual ultimate stress for different lengths of notches.

σ_a: Stress value just before break.

There for:

$$\frac{a_i}{w} = 0 \longrightarrow \sigma_{ur} = \sigma_u \longrightarrow D = 0$$
$$\frac{a_i}{w} = 0 \longrightarrow \sigma_u = \sigma_a \longrightarrow D = 1 \qquad (2)$$

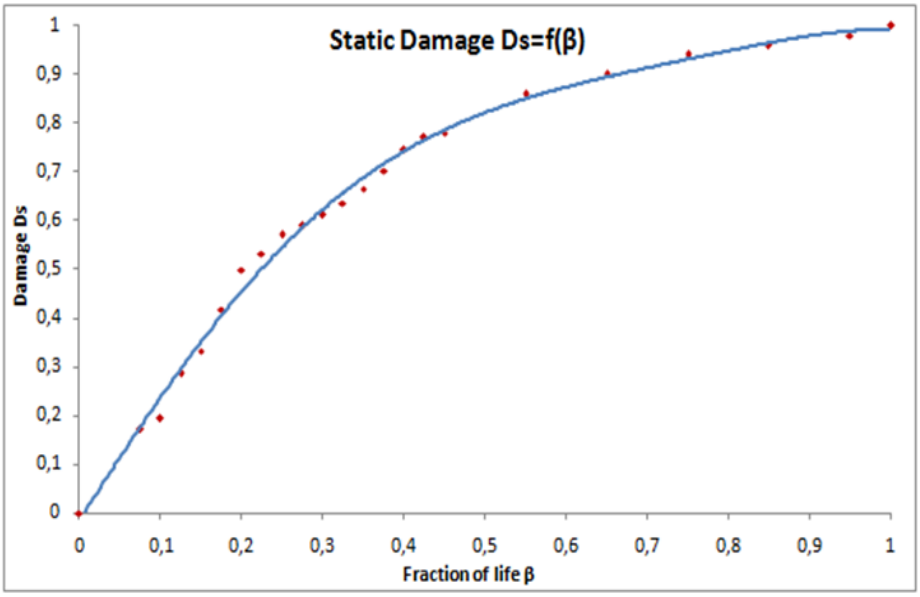


Fig 4: Evolution of the damage as a function of the notch length

The process of damage (fig 4) is represented by a concave curve, which means that the damage accelerates towards the end of the life of the material, and the rupture will take place at D = 1. The increase in damage means the increase in the static tensile strength loss of the ABS test specimens. This loss evolves when the notch length becomes larger. This is a damage with appreciable irreversible deformations, which reduces the ultimate strength of the material.Otherwise, there is another parameter of a static nature, making it possible to follow the evolution of the deterioration of the material. It is the parameter of the reliability "R", which represents the probability of survival of the material [9] [10].

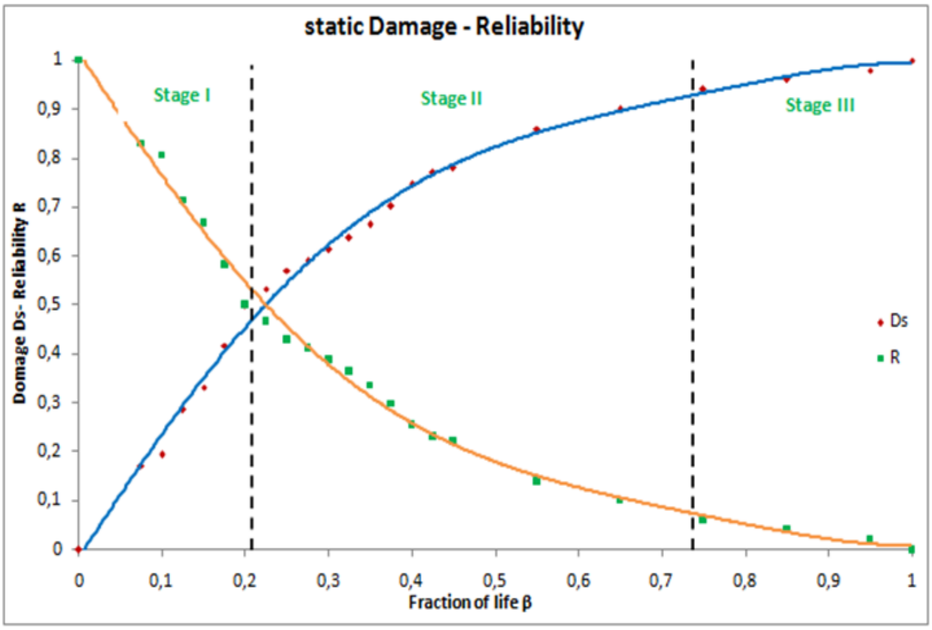


Fig 5: Evolution of damage with respect to reliability as a function of life fraction

The increase in damage is necessarily accompanied by a decrease in reliability (fig 5).At the beginning, we have the initiation zone of the damage (Stage I), at 23% the ABS pierced test pieces and simply notched start to lose their internal resistance and the material begins to get degrading. This is the propagation of the damage, designated by the progressive damage zone (Stage II).At 76% of the damage (24% reliability), the ABS test pieces stressed by tensile stress initiate the zone of abrupt damage, which corresponds to a critical notch length (ac) of 10.50 mm. At this stage III the propagation becomes unstable until the sudden rupture.

IV. Conclusion

This work is based on experimental tests (tensile testing) it has supplemented our theoretical knowledge on ABS.Initially, a series of tests have been accomplished on rectangular standardized test pieces drilled and simply notched from 1 to 14 mm, the aim was to study the mechanical behavior of the ABS polymer.In this paper, we were able to relate the reliability to the damage through the fraction of life. The damage increases as the material studied "Acrylonitrile Butadiene Styrene" loses its resistance, and when the notch length becomes largerThe reliability varies in the opposite direction of the damage and defines the three stages of the propagation of the notch.

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