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Thermo mechanical characterization and damage of polymer materials: Application material Acrylonitrile Butadiene Styrene (ABS)

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Abstract:- Plastic materials occupy a large part in our daily lives because of their ease of installation and relatively low production costs. The rapid technical development and we live brings more and more mechanical engineers to face the problems of damage to materials. However, these problems are even more serious than fatigue cracking often leads to a sudden break often cause accidents. This unfortunately happens all too frequently, due to insufficient knowledge either room service conditions or even damage parameters. This work presents new developments in the field of fracture mechanics and the objective is the evaluation of defects and thus a better estimate of the reliability of the polymeric material structures

Keywords:- polymer breakdown, damage, traction, ABS

I. INTRODUCTION

The polymers offer many features that make it appealing, one can distinguish their corrosion features, their lightness, their low cost, their insulating character their ductility, numerous methods available to implement and shape simultaneously.

Or, if one attaches only to their mechanical properties, their behavior is complex and is a major barrier [1], as potential users find it difficult to be considered when sizing and optimization steps. However, because of the presence of voids in the material, or even damage, cracks can start and propagate to a size causing the collapse of the [2] structure.

To assess the level of damage to a structure subjected to a solicitation, two models exist: the mechanics of the mechanical damage of the rupture [3] and this work is a contribution to the study of the failure mechanism an ABS plate under uniaxial stress through the tensile test.

II. THEORY

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$\gamma_D=(\gamma_{ur}/\gamma_u)^m$

$\gamma_D=(\sigma_D/\sigma_{D0})$, $\gamma_{ur}=(\sigma_{ur}/\sigma_{D0})$, $\gamma_u=(\sigma_u/\sigma_{D0})$

or σ_{D0} is the endurance limit of virgin material, σ_D is the limit of endurance instant of the material (after n loading cycles) σur is the instantaneous value of the monotonic tensile strength of the material, σu is the maximum strength monotonous traction of virgin material, m is an empirical constant. [6] model Bui Quoc [7] provides a correlation between the tensile strength monotonic and cyclic loading, the resistance of a material to a static effect diminishes if it has undergone previous cyclical nature of the application efforts of the static force [8].

We are talking about the reduction of the residual strength of [9] material. σur (equal to σer for polymers) is the ultimate residual stress damaged material after n cycles of loading, σu (equal to σe for polymers) is the ultimate tensile strength of the virgin material, β is the fraction of life and γ = σm / σD0 is the

load level (mean stress σm cyclical) [10]. for polymers, the ultimate stress σu and the stress at the yield σe are identical [11].

Thus, the parameter m is a parameter material with m = 1 for amorphous polymers [12]. The formulation of the damage proposed by Bui Quoc is different from that previously presented by Miner [13]:

$$D=(1-\gamma_D)/(1-\gamma_D^*) \qquad \textbf{Eq (1)}$$

$$\gamma_D=\sigma_D/\sigma_{D0}\ ,\ \gamma_D^*=\sigma_m/\sigma_{D0}$$

σ_D: the endurance limit

σ_{D*}: Critical endurance limit

The damage model resulting fraction is a function of the life of the load and the mechanical properties of the virgin material [14]:

$$D=\frac{\beta}{\beta+(1-\beta)\left[\frac{\gamma-(\frac{\gamma}{\gamma_u})^m}{\gamma-1}\right]} \qquad \textbf{Eq (2)}$$

or $\gamma u = \sigma u / \sigma_{D0}$ is a parameter characterizing the virgin material.

III. EXPERIMENTAL

The tensile tests conducted during the study are provided to characterize the material in terms of its mechanical properties, determine its mechanical properties such as yield strength, Young's modulus, ultimate stress, etc. the purpose of this section is to identify a pattern of behavior of the material that will be useful later in the numerical modeling part.

For this purpose, uniaxial tensile test series were performed on specimens halters. [14], according to the procedure already described in the previous chapter mode. And considering the guidelines prescribed by ASTM D638-03 [15]. To characterize the function of the material temperature behavior, several series of tests were performed in a temperature range from 60 ° C to 170 ° C, through the glass transition temperature which is in the vicinity 110 ° C for each temperature value, the stress-strain curve is drawn to meet the measurands in question for analyzing the thermomechanical behavior of the material. For each temperature, the evolution of the ultimate stress against deformation, so that the change in the Young's modulus were reported.

Figure 1: Test piece dumbbell during a tensile test (left), Rupture of a dumbbell specimen types ASTM D638-03 after static tensile test (right)

IV. RESULTS

In order to characterize the material as a function of the mechanical properties, we conduct tensile testing to extract the various characteristics such as yield strength, Young's modulus, ultimate stress .After Treaty curves produced by the machine traction, and after statistical analysis of the results, we can draw the average curve as follows:

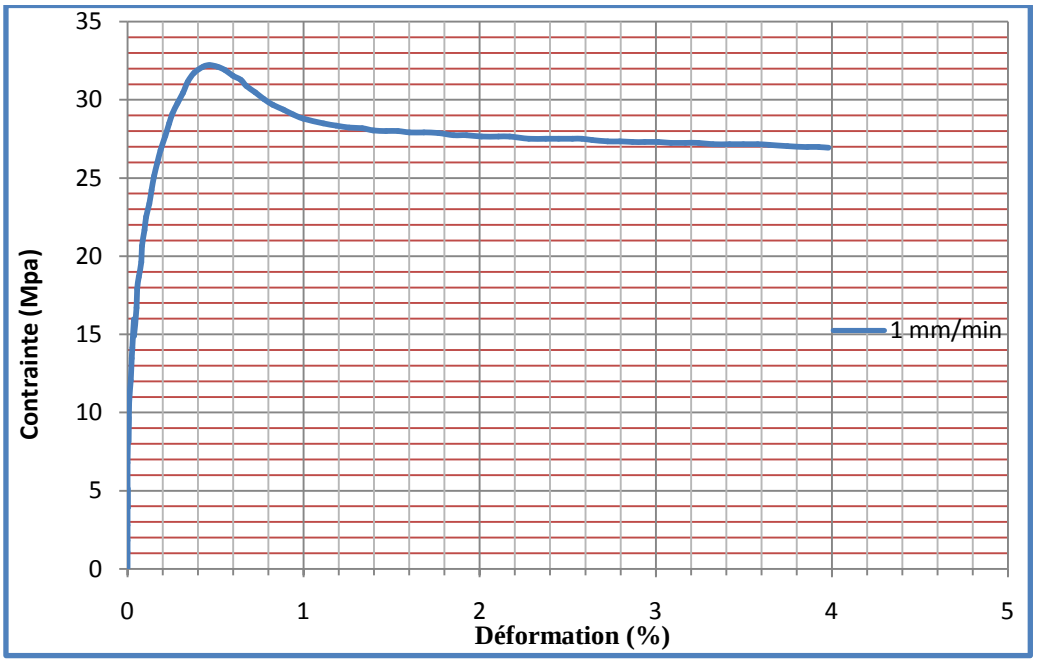

Figure 2: Evolution of the stress versus strain

Tensile tests enable us to trace the evolution of the stress-strain curve up to failure and highlight the typical behavior of polymers in large deformation. At the beginning of the trials, a linear zone is like rating reflecting the proportionality between the applied force and elongation (field of elastic deformation), it allows us to obtain the Young's modulus and yield strength. The obtained value of the Young's modulus is E = 2 GPa, a value comparable with that provided by the literature (from 1.4 GPa to 3.1 GPa), and thus the value of the ultimate stress which is σu = 32MPa, so that the elastic limit which is σ0,2% = 29,77MPa. The material starts to deform beyond the value of 32MPa which has the boundary of the constraint after which more of linear proportionality was observed between the stress and strain; this area is followed by an intrinsic softening portion corresponding to the non-linear plastic deformation and continues with an increase in stress to a maximum after which it decreases to a stabilization of the value as the elongation increases.

- **Effect of temperature on the behavior of ABS**

The behavior of polymers depends strongly on the temperature. They are the site of behavioral transitions that can be associated with different molecular relaxations. From the macroscopic point of view, this translates into more brutal behavior changes in certain temperature ranges. Its influence is apparent on the physical characteristics of the polymers in the behavioral study, specifically when it comes to the study of shaping processes that require significant heat input and efforts must mécanique.Il note however that the behavior of polymers is closely related to a known temperature range glass transition temperature Tg, below which, the configuration of the macromolecular chains is widely immobile.Pour characterization of behavior of the material according to the temperature, several sets of tests were performed in a temperature range from 60 ° C to 170 ° C, passing through the glass transition temperature which is in the vicinity of 110 ° C, for each temperature value, the curve stress-strain is drawn to meet the measurands in question for analyzing the thermomechanical behavior of the material.

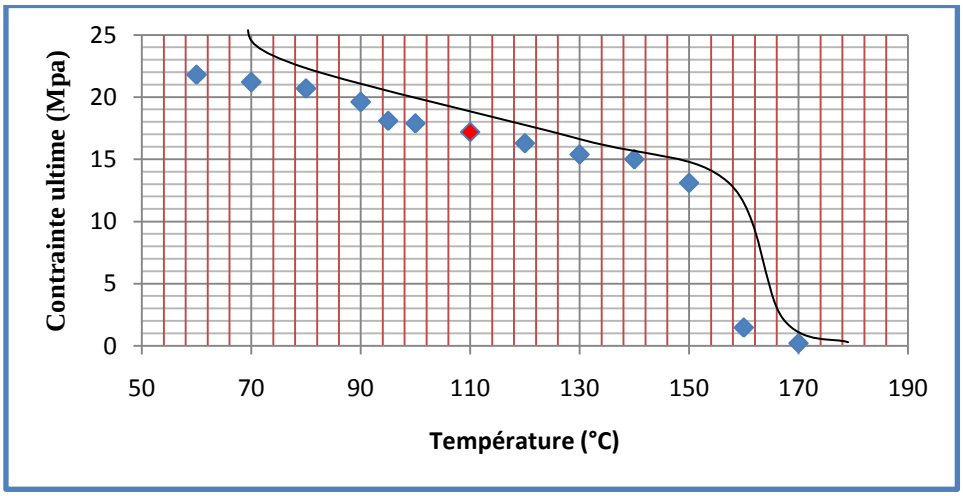

Figure 3: evolution of the ultimate stress versus temperature

From figure which represents the evolution of the ultimate in function of temperature, we can distinguish three important areas:From figure which represents the evolution of the ultimate in function of temperature, we can distinguish three important areas:

• T g (= 110 ° C):

The curve of a progressively decreases gradually as the temperature rises but always keeping the mechanical properties in this area because the polymer molecules are well aligned rows which gives the general ABS good rigidity, good mechanical strength and low deformability

• Tg < T < Tf (= 150 ° C)

In this area the stress continues to decrease rapidly via the temperature increase up to reach a significant value of the temperature (Tm = 150 ° C). In this state the crystalline phase does not change and its structure is identical to what it was at T g (= 110 ° C), the amorphous phase is subjected to thermal activation change causing movement of the molecules, a breaking the bonds of low energy between the molecules and increase the volume of the polymer. This results in a greater ease of movement of the molecules.

• T > Tm (150 ° C)

The material is completely degraded and it's already noticed in the course of the curve beyond the value T = 150 ° C and ABS loses all its mechanical characteristics. The crystalline phase no longer exists because T> Tf, there is no longer an amorphous phase. All molecules (those from the amorphous phase and that from the crystalline phase) form balls. The nodes entanglement disappear crawling, the material flows like a fluid. The polymer is malleable little mechanical strength, low stiffness ... Testing at the vicinity of the melting temperature was not constructive specimen melts before the start of the test, and flows from the jaws the machine due to its weight, and got no results later, the figure shows that the specimens were subjected to temperatures higher than 170 ° C:

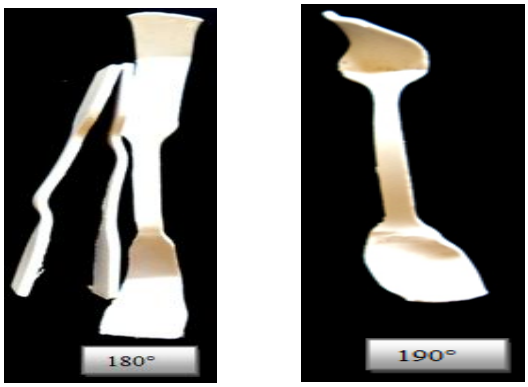

Figure 4 specimens after tensile test at temperatures above 170 ° C

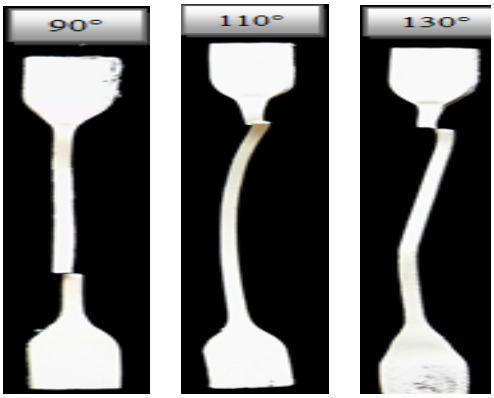

Figure 5: Test subject to tensile tests as a function of temperature

• Assessment of the damage:

All theoretical models of damage require confrontation with results from experiments, hence the need for a standardized formulation of the damage. In the literature, several authors whose BuiQuoc proposed a model of the normalized damage based on the variation of the residual resistance between virgin and her critical condition:

$$D_{Exp} = \frac{1-\gamma_D}{1-\gamma_D^*} \qquad \textbf{Eq (3)}$$

In the case of cyclic loading, fatigue, fractions γ_D and γ_D^* are defined as:

$$\gamma_D = {}^{\sigma_D}/_{\sigma_{D0}}, \qquad et \qquad \gamma_D^* = {}^{\sigma_D^*}/_{\sigma_{D0}} \qquad \textbf{Eq (4)}$$

σ_D the limit of endurance instant, σ_D^* the limit of endurance criticism, σ_{D0} the endurance limit of virgin material. In the case of a static load, the fraction γ_D characterizes the residual strength of the material after a damaging stress. In this case of uniaxial tension coupled with a notch effect, the fraction may be defined showing the static characteristics as follows:

$$\gamma_D = {}^{\sigma_{ur}}/_{\sigma_u} \qquad \textbf{Eq (5)}$$

σ_{ur} the residual ultimate limit,σ_u the ultimate stress static pull of virgin material.

the parameter γ_D^* is a characteristic of the critical tensile strength. In the case of a uniaxial tensile test, it was defined by showing the critical resistance to tensile breaking as follows:

$$\gamma_D^* = {}^{\sigma_{ur}^*}/_{\sigma_u} \qquad \textbf{Eq (6)}$$

σ_{ur}^* the ultimate stress critical.

The expression of the damage made by the equation (Eq6) can be rewritten as:

$$D_{Exp} = \frac{1-\gamma_D}{1-\gamma_D^*} = \frac{1-\frac{\sigma_{ur}}{\sigma_u}}{1-\frac{\sigma_{ur}^*}{\sigma_u}} \qquad \textbf{Eq (7)}$$

Thus defined, the normalized damage is calculated through experimental measurements on perforated specimens. And its value is between 0 and 1.

The following curve shows the variation of damage depending on the dimensionless ratio of the temperature.

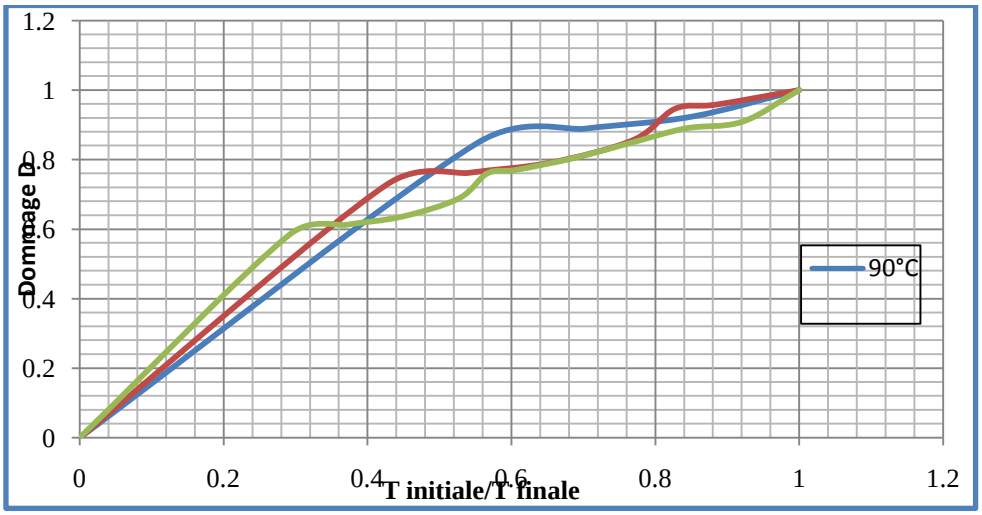

Figure 6 : damage evolution depending on the fraction of life β = T (initial) / T (final)

The above curve represents the change in terms of damage to temperature versus dimensionless ratio of the temperature as we notice that each curve can be divided into three parts that define stages and the following table summarizes the different features:

	90°C	**110°C**	**150°C**
Stade I	• β = (0 ; 0,6) • D= (0 ;0,88)	• β = (0 ; 0,44) • D= (0 ; 0,76)	• β =(0 ;0,30) • D=(0 ;0,6)
Stade II	• β = (0,6 ; 0,88) • D=(0,88 ;0,94)	• β =(0,44 ;0,84) • D=(0,76 ;0,96)	• β =(0,30 ;0,92) • D=(0,6 ;0,92)
Stade III	• β = (0,88 ; 1) • D= (0,94 ;1)	• β =(0,84 ;1) • D=(0,96 ;1)	• β =(0,92 ;1) • D=(0,92 ;1)

The results clearly show for each temperature (90 ° C, 110 ° C, 150 ° C), the development of standardized experimental damage according to β = T (initial) / T (final). Whatever the temperature, the damage gradually increases from 0 (virgin material) to its normalized value of 1.

- In phase 1, ABS keeps a good mechanical strength. This is attributed to the morphology of the crack, which has a continuity of matter through micro fibrils [TIJSS, 1995] and gives the material a nearly intact residual strength.
- In phase 2, this area is a progressive increase in damage.
- Finally Phase 3 for β greater than 0.9, the damage is rapidly accelerating until it breaks. By analogy to cracking, the beginning of this stage is the condition of instability leading to rupture.

Indeed for low β, the material still has good resistance, which in terms of industrial removes any gain an accurate assessment of the damage. By cons, for heavy loads, β large, the level attained damage can lead to material failure (critical injury: a phase of instability of the material making it unfit for service). Hence the need to accurately predict the damage for high β.

IV. CONCLUSION

The thermal damage tests were preceded by thermophysical characterization tests to determine the glass transition temperature of ABS, as well as its melting temperature. Then tensile tests on fracture under controlled temperature were carried out in order to note the influence of temperature on the structural behavior of the material;

• The glass transition temperature of ABS is Tg = 110 ° C,
• Its melting point is Tf = 196.19 ° C

• For temperatures vary between 20 ° C and 170 ° C, a degradation of the mechanical properties is observed, a drop of the ultimate stress of the 99.5% in order from room temperature to 170 ° C,
• Elongation proportionally increases with the temperature, growth accelerates after the passage of the Tg.

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