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Mechanical behavior study of an ABS's sample damaged artificially

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ABSTRACT: The knowledge of the mechanical behavior is essential to predict the lifetime of components in order to avoid any sudden break in service. In this context arises our study which aims firstly to study the behavior of an ABS plate reliability(acrylonitrile butadiene styrene) artificially damaged and subjected to uniaxial tensile loading and with the aim to predict the lifetime and know the limits that must not be exceeded as this can cause failure. To measure the criticality of the damage we based this work on the theory of the unified damage, secondly to consider the stress concentration phenomenon in the sample in the presence of a discontinuity. We will also treat in this manuscript the evaluation of the stress intensity factor by an analytical calculation using the method of superposition about a combined defect. The results obtained in the light of this study allowed us to determine the different stages of damage and critical defect size which leads to the ruin of the structure.

KEYWORDS: Damage, ABS, unified Theory, Reliability, stress intensity factor, Tensile testing.

1 INTRODUCTION

The frequent use of materials required the development of a way of calculation to prevent the fragile fracture that these materials could undergo, hence the birth of fracture mechanics that studies the interaction between the geometric discontinuity and the surrounding environment, as well as the evolution of this discontinuity.

Avoid disruptions in service is one of the major concerns of engineers. A good command of mechanical behavior of materials is essential to achieve this result. This suggests the knowledge of the stress and strain field that will let to determine the default's propagation kinetics and the critical size beyond which the unstable fracture occurs. And therefore predict the lifetime of materials and the preventive maintenance required. [1] [2] [3]

In this work, we are focused primarily on the study of a combined two-dimensional defect (variable diameter hole and a fixed double notch) artificially achieved on a rectangular specimen ABS.

2 STUDY DESIGN

In the conducted study we will be interested to rectangular samples of dimensions 40*150*1.46 $mm^3$with defects combined with hole diameter ranging from 3 to 30mm and a double notch of 1mm in length from the each edge as shown in Fig.1 and subjected to uniaxial loading with a view to determining the level of default stress concentration and the damage mode.

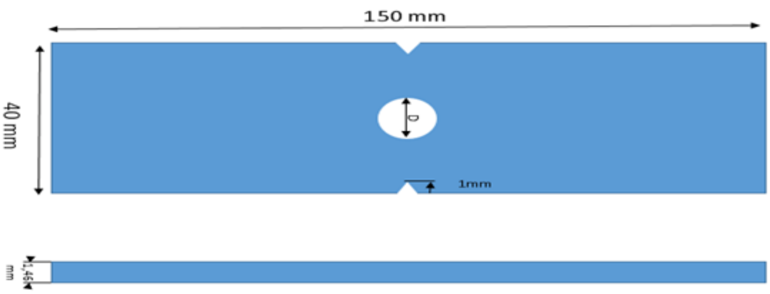

Fig. 1. The specimen dimensions study

The material of the sample is a polymer of the ABS type whose mechanical properties are:

Table.1. The mechanical characteristics of ABS

Module de Young	σ_e	σ_{ur}	**coefficient de poisson**
E=2GPa	29,779 MPa	34,39MPa	ν=0.43

3 Results and analysis

3.1 Study of Damage

3.1.1 Static uniaxial tensile testing

We realized holes of varying diameter from 3 to 30 mm and double notch with length 1mm each one on the studied rectangular sample, then, we applied a tensile test until rupture with a transverse velocity of 1mm/min for three specimens for each size of defect.

The traction diagrams obtained describing the evolution of the constraint according to the deformation for each level of damage is given by the fig.2.

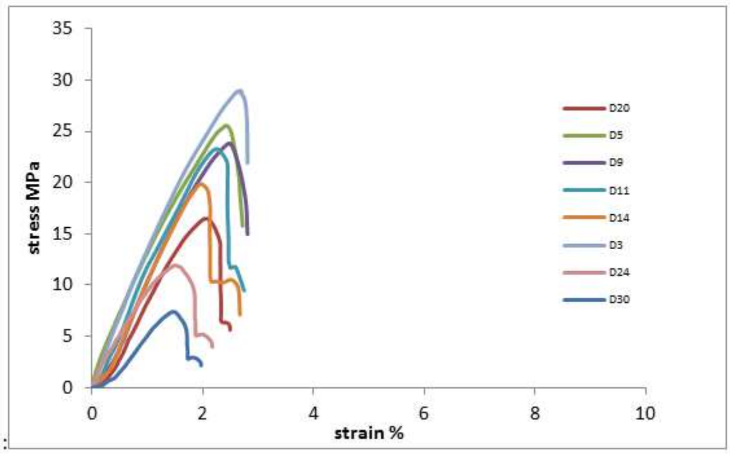

Fig. 1. Traction diagrams of the pressure applied according to the deformation for the test-tubes with hole and double notch

We notice according to the results of the traction tests that the material characteristics decrease with the evolution of the size of the defect. These properties include the elastic limit, the ultimate stress and the deformation at failure

For example we find a value of the ultimate stress of 29.7 MPa for a size of defect of 5mm. This value falls to 7.42 MPa for a size of defect of 30 mm. Figure 3 shows the evolution of the ultimate stress according to the size of the defect.

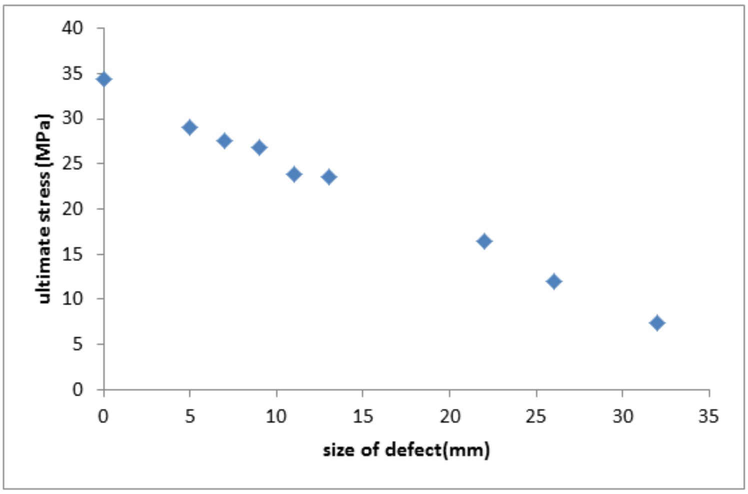

Fig. 2. Evolution of the ultimate constraint according to the size of the defect

We deduct that the mechanical properties of the material are influenced by the effect of the combined defect and consequently the material tends to become more fragile which can lead to a rupture increasingly brutal.

3.1.2 CALCULATION OF THE STATIC DAMAGE

To quantify the damage of our studied specimen we are going to adopt the model of the static damage which consists in determining the evolution of the stress according to the fraction of life. [4] [5]

Thus the variable of the damage can be defined as:

$$Ds = \frac{1-\frac{\sigma ur}{\sigma u}}{1-\frac{\sigma a}{\sigma u}} \qquad \text{(I)}$$

And the fraction of life is defined as

$$\beta = \frac{a}{w} \qquad \text{(II)}$$

With

a: the size of the defect in our case it is the sum of the diameter and the length of the double notch;
W: the width of the beam.
σ_{ur}: the residual ultimate stress;
σ_u: the ultimate stress of virgin material;
σ_a: the stress just before the failure.

The evolution of the damage phenomenon between virgin state and the damaged state follows the curve presented in the fig. 4 below:

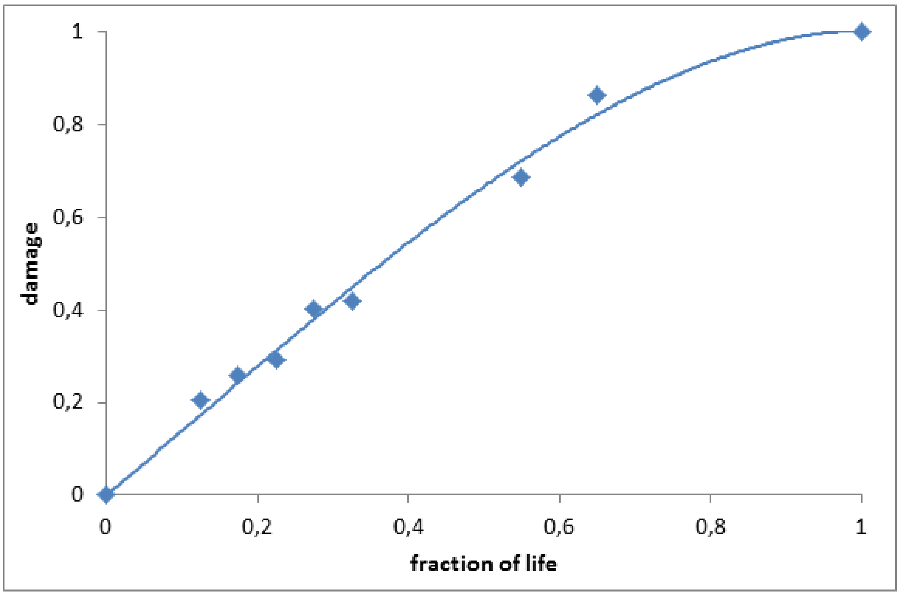

Fig. 3. Evolution of the damage according to the fraction of life

According to fig.4 we can say that the damage increases proportionally with the fraction of life between the initial state which coincides with the virgin state of the material and the final state where the material is totally damaged. It is a question in our case of a fragile damage which explains the appearance of irreversible deformation leading to a material resistance decreasing.

STATIC DAMAGE STATIC-RELIABILITY

The aim of damage research is to reduce the risk of sudden cracks growth in the service components. Therefore, it is necessary to reduce the probability of failure, hence the interest of using the reliability theory to assess the probability of sudden damage.

There is a relation between the damage and the reliability which is illustrated by the following equation which allowed us to construct the static reliability curve. The latter has allowed us to draw the static reliability curve

$$Rs(\beta) + Ds(\beta) = 1$$

The fig. 5 below shows the damage curve superimposed with that of reliability.

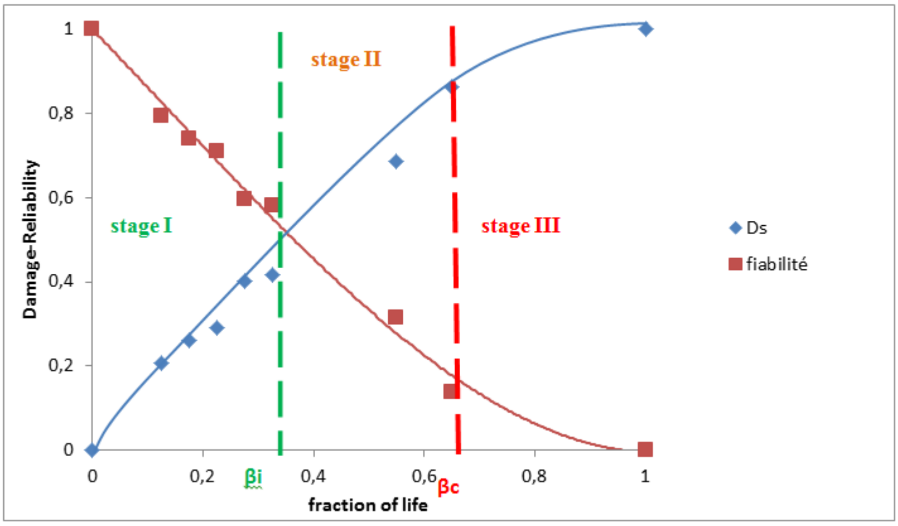

Fig. 4. Curves damage statics-Reliability of the specimen with hole and double notch

We observe according to the curves Damage-Reliability that reliability progresses in the opposite direction of the damage.

It is noted that before the point of intersection of the curves damage-reliability respectively grows and decrease in an accelerated linear way, it concerns the stage I of damage. Just after this point we note stabilization, the curves evolve gradually it is stage II. Stage III where$\beta>0.65$ the damage reaches its maximum sample can constantly express a brutal rupture that requires a preventive maintenance on the level of this stage.

To recapitulate, the various stages of damage of our sample are summarized as follows:

- Stage I : $\beta \in [0, 0.4]$: stage of initiation the damage grows in a linear way
- Stage II: $\beta \in [0.4, 0.65]$: stage of starting the damage grows gradually
- Stage III: $\beta>0,65$ stage where the damage evolves quickly and the propagation of the defect becomes brutal

3.1.3 CALCULATION OF THE DAMAGE BY UNIFIED THEORY

Tensile tests were used to calculate the residual strength, which decreasing with the β fraction of life

It makes more sense to conduct a damage calculation that takes into consideration the conditions and level of loading: these are factors that influence the progression of the damage. In the literature, there are models of the damage coupled with the moderate residual resistance, among these theories we find the law Bui Quoc also called "Unified Theory" which links the damage to the variation of the endurance limit as a function power whose form is: [6]

$$Yd = \left(\frac{Yur}{Yu}\right)^m \qquad \text{(III)}$$

With

$Yu = \frac{\sigma u}{\sigma 0}$ and $Yur = \frac{\sigma ur}{\sigma 0}$

σ_0 : limit of endurance residual of the virgin material which is equal to the residual ultimate constraint multiplied by a coefficient$\alpha=\frac{1}{safety coefficient of the materiel}$The safety factor used for this material is egal to 2.5.

The theoretical model of the unified theory linking the damage to the loading level is given by the following equation [6]:

$$D = \frac{\beta}{\beta+(1-\beta)\times[\frac{Y-\left(\frac{Y}{Yu}\right)^m}{Y-1}]} \qquad \text{(IV)}$$

$\beta = a/w$ and m= 1 for polymers.

The different curves of the damage by unified theory which is calculated using the relation (a) depending on the β fraction of life is illustrated in Fig.6. Each curve corresponds to a level of loading.

It is noticed that the curve of damage approaches the bisectrix which represents the damage of Miner when the loading increases (γ grows). Consequently the law of miner presents the most critical damage compared to the damage of the unified theory and thus it presents more security

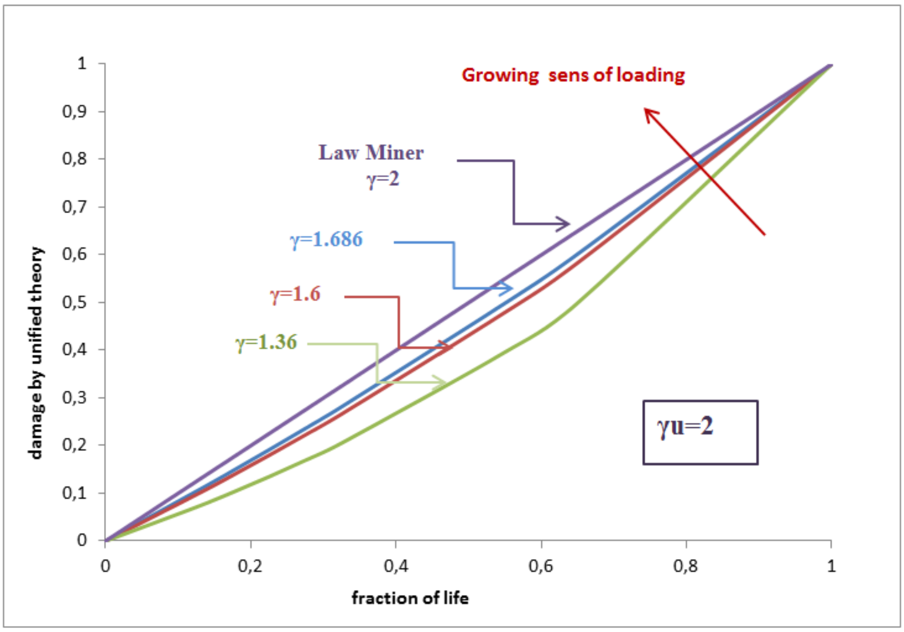

Fig. 5. Curves representing the damage according to the theory unified as function to the fraction of life β for various levels of damage

3.2 CALCULATION OF THE CONCENTRATION OF THE STRESS SAMPLES IN ABS SAMPLES DAMAGED ARTIFICIALLY

3.2.1 CALCULATION OF THE COEFFICIENT OF CONCENTRATION OF CONSTRAINT KT

The stress concentrations constitute a concern major during the conception of the industrial components. This phenomenon is accentuated on the level of the discontinuities or in the zones which contain a geometrical modification. These zones constitute a nest of starting of cracks which will be the object of a brutal rupture thereafter.

The calculation of the coefficient of concentration of stress supposes the knowledge of the nominal constraint and the real constraint. It can be determined analytically using mathematical formulas or numerically by a finite element method. In this present work we are going to determine the real constraint at the bottom of the crack numerically. The coefficient of concentration of stress is defined as being the report between the maximal stress and the nominal stress:

$$K_t = \frac{\sigma_{max}}{\sigma_{nom}}$$

The concentration coefficient of stress of our test specimen according to the size of the defect is represented by the curve of the figure.7

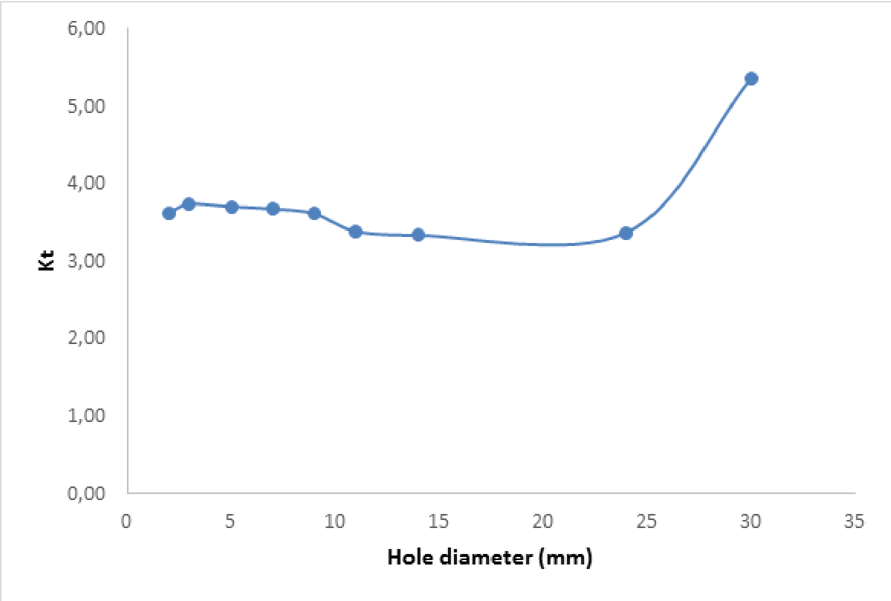

Fig. 6. Evolution of concentration coefficient of stress according to the size of the default

The coefficient of concentration of stress appears stable although the size of the default increases until reach the size of 26 mm beyond this value he grows in accelerated way.

We can conclude that the presence of the hole of lower diameter does not affect the distribution of constraint at the bottom of the notch and consequently the maximal stress stays approximately constant what explains the stability of the concentration coefficient of stress. Whereas beyond the diameter 24mm, the presence of the hole contributes to the increase of the concentration of stress at the bottom of the notch which justifies the increase of the value of Kt.

3.2.2 Calculation of stress intensity factor

We cannot speak about fracture process without evoking the stress intensity factor. It constitutes a genuine engine of the damage since it makes possible to predict the kinetics of propagation of the defaults and consequently evaluates the harmfulness of the defect. [7]

This last part will be devoted to the calculation of the FIC of our structure. It is about a calculation by the principle of superposition because it is about a combined default. This method consists in bringing back with the problem dealt to a succession of problems whose solutions are known Fig.8.

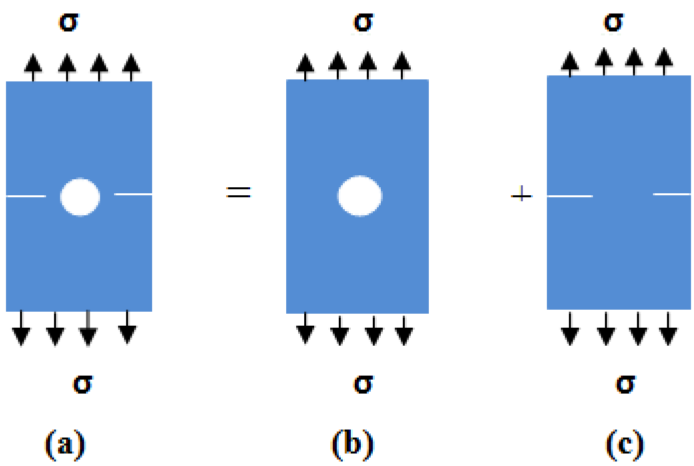

Fig.8.The principle of superposition

We apply this method to our tests, one finds:

$$K_I(a)=K_I(b)+K_I(c) \quad \text{(VI)}$$

After the calculation we find the results presented in the fig. 9:

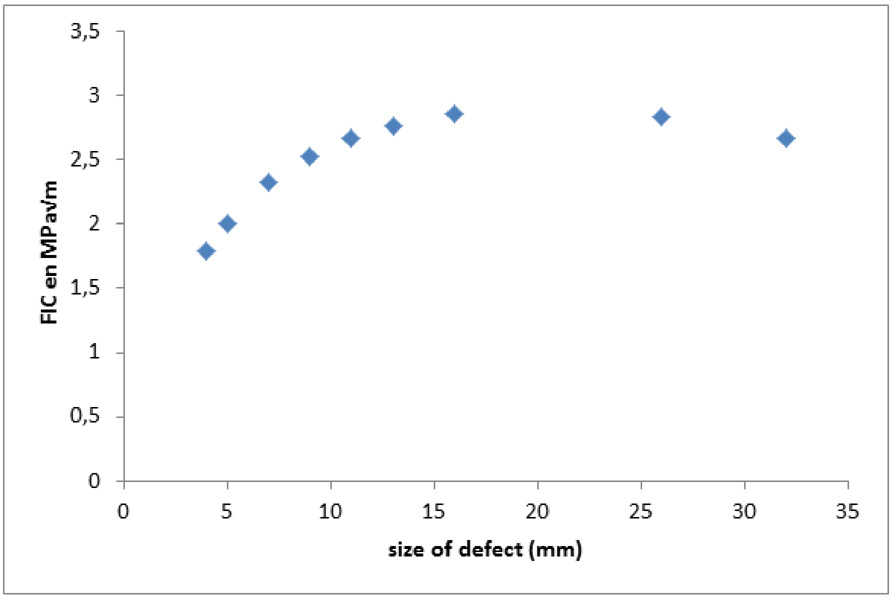

Fig.9. Evolution of the stress intensity factor according to the size of the defect

We notice that the value of the stress intensity factor increases with the size of the default until reach its critical value which is of KIc=2.8 MPa$\sqrt{m}$ it corresponds to a default of 26mm (diameter of the hole of 24mm).

Beyond this size, the stress intensity factor drops due to the fact that the hole is near the bottom notch and disrupts the constraint distribution in this zone, whence the result obtained.

4 CONCLUSION

This work presents a study of the mechanical behavior of ABS rectangular test piece having discontinuities and subjected to a uniaxial tensile testing. To characterize the damage of the structure a study of the static-reliability damage has been realized thus the three stages of the damage have been identified.

Because of the influence of load damage we calculated the damages by the unified theory that we have compared to that of Miner and we observed that the curve traced by unified theory are less critical than the curve of the Miner damage.

The second part of this work was dedicated to the study of the distribution of stress in the studied structure by calculating at first the coefficient of concentration of stress for every size of the default. Then we verify that the concentration of stress is maximal at the bottom of notch, secondly by determining the FIC by an analytical calculation basing on the superposition principle.

Comparing the study of the damage and the results of the linear mechanics we notice that the results are in good concordance and that from the default size of 26mm specimen may at any time express a brutal rupture. Beyond this size appears the unstable zone and therefore the linear mechanical formulas are no longer valid

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