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Evolution of Crack Tip Plastic Zones of Specimen Size with Yield Stress

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Abstract- With the face of crack, there exists a plastic zone which affects the evolution of the aforesaid the crack. The opening of this crack or the spacing is in direct relationship with this zone. Irwin proposed a simple model by applying plane constraints to the point of the crack. In the same way for Rice who has her concept establishes. We will see the influence of the spacing criticizes of a crack of an alloy (Al-Cu) used in aeronautics on tenacity and the strength parameters in bottom of crack, let us consider two international standards of them Russian and English. We complete our work by simulation by finite elements (FE) by Castem2001.

Keywords- *crack, simulation, tenacity, point of the crack, plastic zone.*

I. Introduction

Approaches to introducing a length scale in ductile fracture modeling are presented in Mediavilla et al. (2006), Bargellini et al. (2009), Cazes et al. (2010), and Huespe et al. (2009). In Huespe et al. (2009), we presented a finite element method with a finite thickness embedded weak discontinuity to analyze ductile fracture problems that was restricted to small geometry changes. An embedded weak discontinuity was introduced when the loss of ellipticity condition was met. A material length scale was introduced to give the resulting local-ized deformation band a specified thickness. Within the band, the deformation is specified to be homogeneous and is gov-erned by the pre-localization constitutive relation. As a consequence, convergent calculations of the history of deformation through localization and the creation of new free surface can be carried out. It was also shown that in the limit of vanishing band thickness a cohesive surface formulation is approached with the important difference that for a finite band width the separation relation can be hydrostatic stress dependent. In essence, the methodology allows for a unified framework for ana-lyzing the transition from a weak discontinuity to a strong discontinuity.

Here, we extend the formulation in Huespe et al. (2009) to finite deformations. This is of importance in ductile fracture analyses since large strains generally occur prior to fracture, at least locally. As in our small deformation analyses, the calculations carried out are based on the rate independent constitutive relation for progressively cavitating solids introduced by Gurson (1975) and as modified by Tvergaard (1981, 1982) and Tvergaard and Needleman (1984). Recent comparisons of numerical in MS Word 2003 and saved as “Word 97-2003 & 6.0/95 – RTF” for the PC, provides authors with most of the formatting specifications needed for preparing electronic versions of their papers. All standard paper components have been specified for three reasons: (1) ease of use when formatting individual papers and (2) automatic compliance to electronic requirements that facilitate the concurrent or later production of electronic products. Margins, column widths, line spacing, and type styles are built-in; examples of the type styles are provided throughout this document and are identified in italic type, within parentheses, following the example. Some components, such as multi-leveled equations, graphics, and tables are not prescribed, although the various table text styles are provided. The formatter will need to create these components, incorporating the applicable criteria that follow.

II. Material and Procedure

The material used to better reflect the formability of materials, since they reflect two important plastic properties of metals (see table 1). The numerical designation has been adopted in the NF A 02-104 (1980) and is identical to the designation of EN 485-2. EN AW-2024 [AlCu4Mg1] 4% copper, 1% magnesium.

Table 1: mechanical properties [25]

alloy	*(MPa)* σ_y	*σ(MPa)*	*A(%)*
2024-T3	*343*	*480*	*17*

The theory of critical crack spacing (Crack-opening displacement, abbreviation CTOD.) was first formulated by Wells [26]. The critical distance from the lips of a crack is considered a test of resistance to boot tears. This theory of the critical crack spacing is especially applicable in the case of steels where the plasticized zone at the crack tip becomes important and makes possible the separation of the lips of the cracks years increasing its. We show that the lamination produces a blunting the crack tip whose surfaces differ at this level of δ, called COD (Crack Opening Displacement).

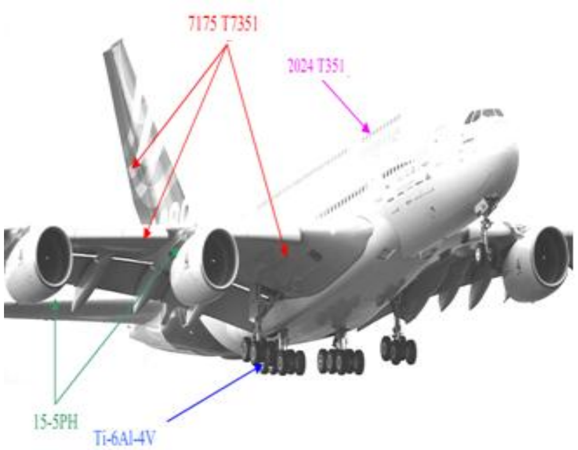

Fig. 1: Alloy of of plaine (2024T351).

From the expressions of displacement di terms and taking into account the plastic zone correction, this is expressed as:

$$\delta = \frac{8a}{\pi}\frac{\sigma_y}{E}\ln\sec\left[\left(\frac{\pi\sigma}{2\sigma_y}\right)\right] \quad (1)$$

Small enough For a constraint σ to σ_y , δ then :

$$\delta = \frac{K_I^2}{E\sigma_y} \quad \text{with} \quad K_I = \sigma\sqrt{\pi a} \quad (2)$$

Indeed the equation (1) can be written in the form of a Taylor expansion:

$$\delta = \frac{8a\sigma_y}{E}\left\{\frac{1}{2}\left[\frac{\pi\sigma}{2\sigma_y}\right]^2 + \frac{1}{12}\left[\frac{\pi\sigma}{2\sigma_y}\right]^4 + \frac{1}{2}\left[\frac{\pi\sigma}{2\sigma_y}\right]^6 + \cdots\right\} \quad (3)$$

The Calculations of Burdekin and Stone [27] show that the crack spacing δ (at the bottom of the real crack) is given by the displacement in x ± a is: We Whereas the first term only.

$$\delta = \frac{\pi a}{E}\frac{\sigma^2}{\sigma_y} \quad (4)$$

Using the model proposed by Dugdale and Barenblatt [28] [29], we link the critical crack spacing and the fracture energy per unit area G_C.

$$G_C = \frac{\pi\sigma^2 a}{E} \quad (5)$$

Comparing equations (4) and (5) we obtain the relation:

$$G_C = \sigma_y \delta c \quad \text{if} \quad {}^{\sigma}/_{\sigma_y} < 1 \quad (6)$$

The value of the total deformation ε can be obtained experimentally by measuring the distance of cracking on a gauge length equivalent (ie twice the value of the spacing of cracks).

$$\epsilon = \frac{\partial\delta}{2\delta} = \frac{1}{2}Log\delta \quad (7)$$

Recently, Carboni [30] and Yamada and Newman [31] used micro-strain gauges glued near the front of the crack locally to detect the small change of convenience for small cracks. In elastoplasticity, the crack tip becomes blunt and some authors have proposed using the crack opening as a parameter of fracture mechanics. The CTOD, crack or gap δ, has been defined from the displacement of the crack tip, measured at the intersection of the boundary of the plastic zone with the lips of the crack. There are many ways to calculate this distance δ. For example, Tracey has proposed to define this distance at the intersection of two lines passing at 45 ° to the axis and the lips of the crack (see figure 2). Fellows and Nowell [32] used the method of Moiré interferometry to measure the displacement of the lips of the crack to detect the closed position. Chang et al. [33] proposed a technique for detecting acoustic emission to detect the closure of small cracks.

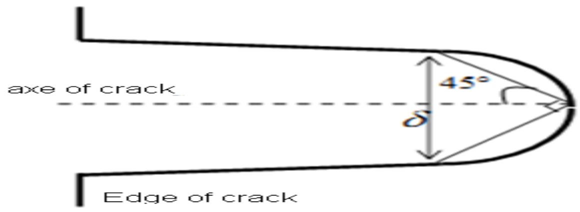

Fig.2: COD

The main quantities in fracture mechanics is the stress intensity factors and energy release rate. These quantities can be connected to each other, we propose to calculate the energy release rate using the method presented above Gθ. Then we will compare the results with analytical results on geometrical configurations known. After showing the good accuracy of the method Gθ, we study the influence of the mesh on the results. For Linear isotropic elastic material, the value of the integral J is easily obtained in plane strain:

$$J = \frac{1-\vartheta^2}{E}K_I^2 \quad (8)$$

and in plane stress:

$$J = \frac{1}{E}K_I^2 \quad (9)$$

To determine the accuracy and robustness of the method Gθ, we will compare the results obtained by this method with known analytical results for certain geometric configurations.

For single specimens, and elasticity, it is possible to calculate stress intensity factors by analytical formulas that can be found in several books. Then, the energy release rate is calculated using the following formulas:

Specimen SEC (Single Edge Crack):

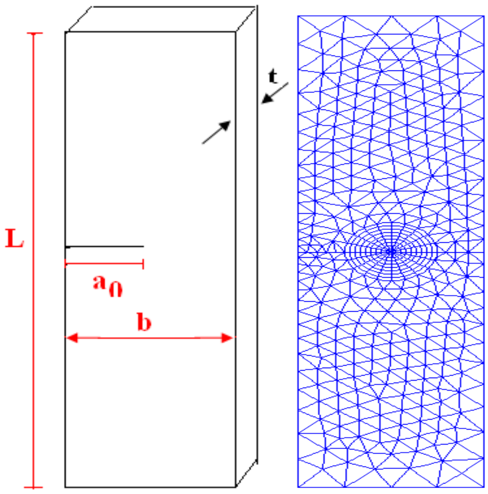

Fig. 3 : Single Edge Crack Specimen

It is a semi-infinite plate, subjected to a stress homogeneous, and having a crack length of side 2a (see fig. 3). For this type of geometry, the stress intensity factor for pure opening mode (mode I), is:

$$K_I = 1{,}122\,\sigma\sqrt{\pi a} \tag{10}$$

$$G = \frac{K_I^2 + K_{II}^2}{E'} + \frac{K_{III}^2}{2\mu} \tag{11}$$

$$E' = \begin{cases} E' = E \quad \text{in plane stress} \\ E' = \dfrac{E}{1-\nu^2} \quad \text{plane déformation (strain)} \\ \mu = \dfrac{E}{2(1+\nu)} \quad \text{in shear} \end{cases}$$

This method is available to the technical progress of the crack developed by Park [34]. This method is still effective and widely used in recent studies [35].

In a two-dimensional diagram, the elastic behavior of a material connects the constraints σ_{11} □, σ_{22} □and σ_{12} to deformation ε_{11} □, ε_{22} □and ε_{12} In the case where the material is isotropic, the elastic behavior of the material is characterized by its Young'smodulus (E) and its Poisson's ratio (□). For a state of plane stress, the stress-strain relationship can be written :

$$\begin{bmatrix}\sigma_{11}\\ \sigma_{22}\\ \sigma_{12}\end{bmatrix} = \frac{E}{1-\nu^2}\begin{bmatrix}1 & \nu & 0\\ \nu & 1 & 0\\ 0 & 0 & \dfrac{1-\nu}{2}\end{bmatrix}\begin{bmatrix}\varepsilon_{11}\\ \varepsilon_{22}\\ \varepsilon_{12}\end{bmatrix} \tag{12}$$

and in the case of a state of plane deformation, it is written:

$$\begin{bmatrix}\sigma_{11}\\ \sigma_{22}\\ \sigma_{12}\end{bmatrix} = \frac{E(1-\nu)}{(1+\nu)(1-2\nu)}\begin{bmatrix}1 & \dfrac{\nu}{1-\nu} & 0\\ \dfrac{\nu}{1-\nu} & 1 & 0\\ 0 & 0 & \dfrac{1-2\nu}{2(1-\nu)}\end{bmatrix}\begin{bmatrix}\varepsilon_{11}\\ \varepsilon_{22}\\ \varepsilon_{12}\end{bmatrix} \tag{13}$$

Stress values plotted on the curves of simulated behaviors for various distributions studied were calculated using the relation of strength of materials giving the maximum tensile stress as a function of the applied load P. □

$$\sigma = \frac{F}{S0} \tag{14}$$

Critical factor of stress intensity (Tenacity):

$$K_{IC} = \frac{P_C}{t\sqrt{b}}\, f_2\left(\frac{a}{w}\right) \tag{15}$$

The decomposition of the spacing critical crack(CTOD) an elastic portion and a plastic part.

$$\delta_c = \delta_e + \delta_{pl} \tag{16}$$

III. Numerical Simulation by the Code CASTEM 2001

Manufacturers demonstrate the need for modeling tools and / or simulation of welding, methodological or predictive, to improve the reliability of assemblies. A major challenge for development teams of structure lies in the prediction of the mechanical effects of welding (stresses and deformation). Castem 2000 use finite element method. For an elastoplastic material, it is possible to represent the shape of the plastic zone at the crack tip. Indeed, in plane strain, the theoretical models of the plastic zone at the crack tip provide a form resembling butterfly wings.

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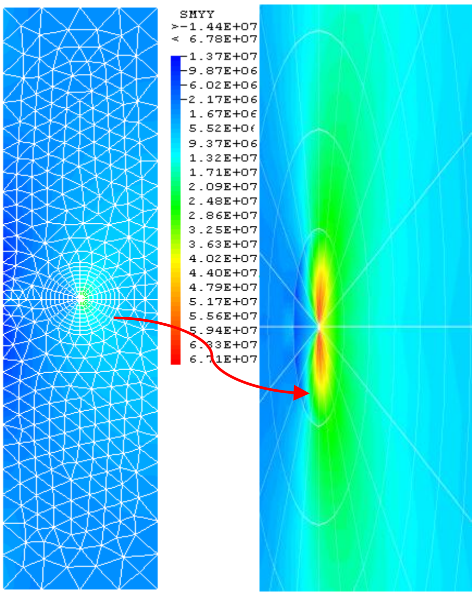

Fig. 4: Records of stresses SMYY

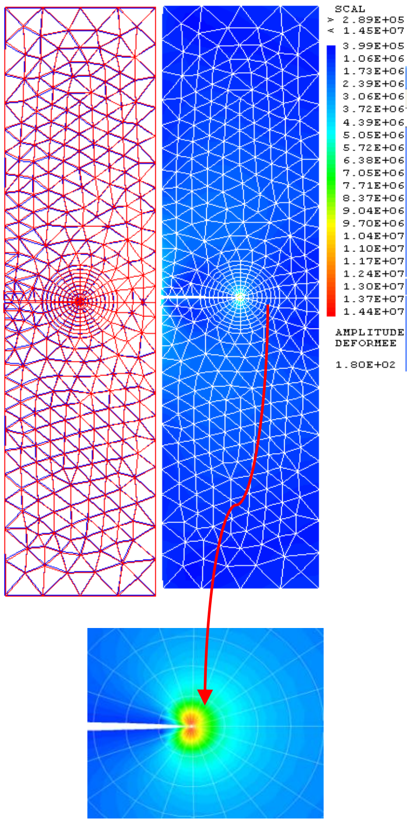

Fig.5: deformation and Von Mises stress after 10 seconds of loading with the crack tip plastic zones

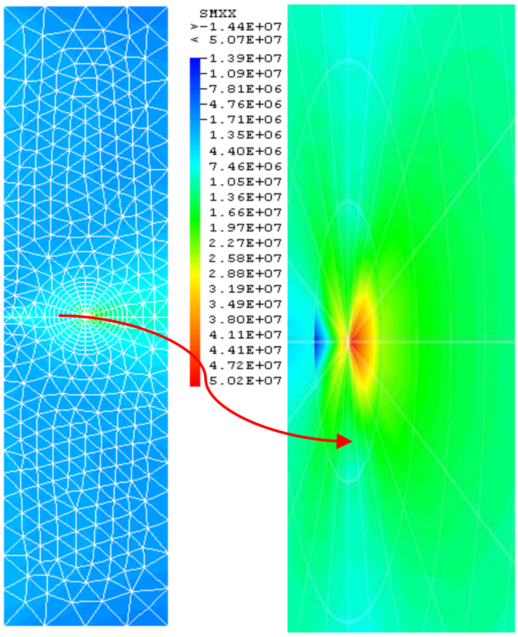

Fig. 6: Records of constraints SMXX

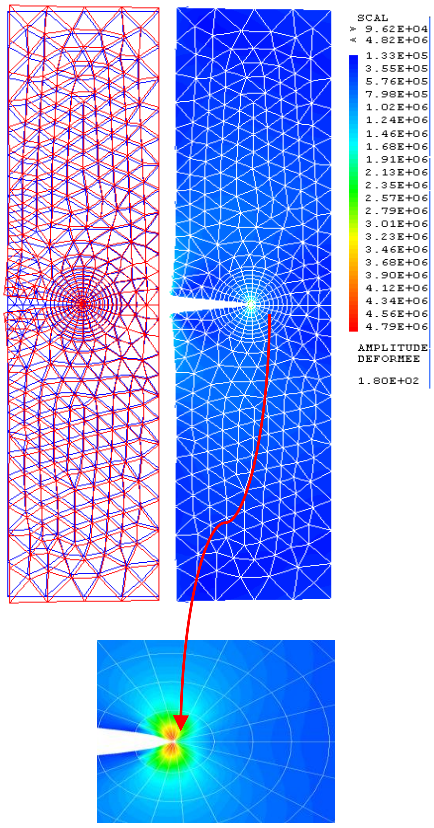

Fig. 7: deformation and Von Mises stress and after 50 seconds of loading with the crack tip plastic zones

TABLE 2: RESULTS OF SIZE PLASTIC ZONE WITH CTOD

Load	a mm	Re=250 MPa		Re = 450 Mpa		Re= 650 Mpa	
		δc mm	Rp mm	δc mm	Rp mm	δc mm	Rp mm
σ^C = 200 MPa	2.5	0.0089	0.8791	0.0036	0.7635	0.0024	0.3234
	5	0.0178	1.7581	0.0073	1.5270	0.0048	0.6468
	7.5	0.0267	2.6372	0.0109	2.2906	0.0072	0.9702
	10	0.0356	3.5163	0.0145	3.0541	0.0096	1.2936
	12.5	0.0445	4.3953	0.0182	3.8176	0.0120	1.6170
	15	0.0534	5.2744	0.0218	4.5811	0.0144	1.9404
	17.5	0.0623	6.1535	0.0255	5.3446	0.0168	2.2638
	20	0.0712	7.0325	0.0291	6.1081	0.0192	2.5872

TABLE 3: RESULTS OF SIZE PLASTIC ZONE AND CTOD WITH YIELD STRESS AND LENGTH OF CRACK

a(mm)	Re(mm)	δc (mm)	Rp(mm)
2.5	250	0.0089	5.5902
5	300	0.0126	5.0000
7.5	350	0.0150	4.5291
10	400	0.0168	4.1421
12.5	450	0.0182	3.8176
15	500	0.0193	3.5410
17.5	550	0.0202	3.3023
20	600	0.0209	3.0940
22.5	650	0.0216	2.9106

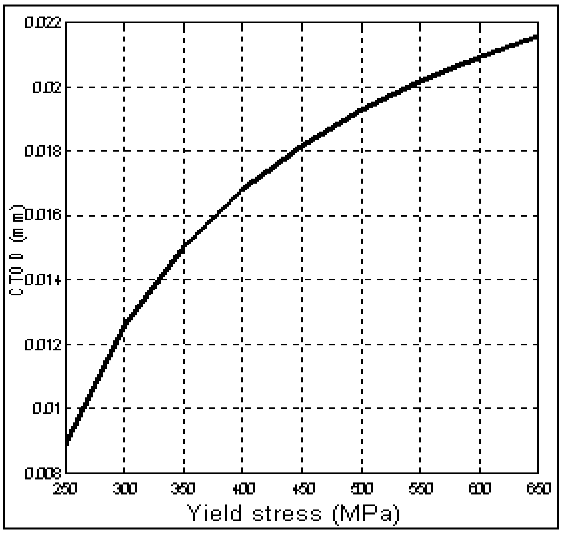

Fig. 8: CTOD function of yield stress

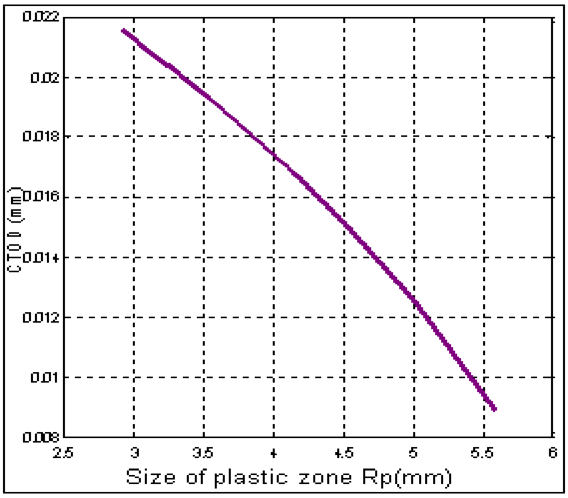

Fig. 9: CTOD and size of plastic zone

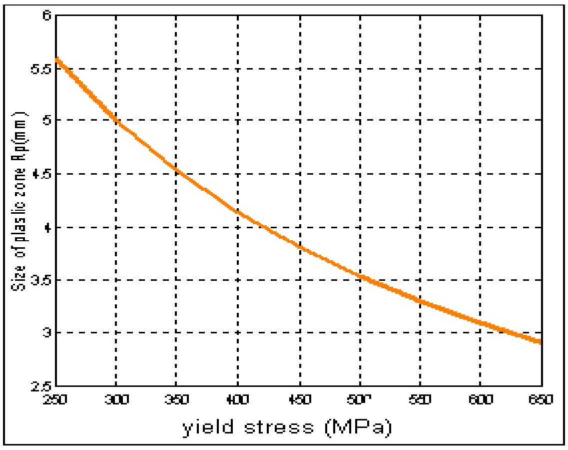

Fig. 10: size of plastic zone (Rp), function of yield stress

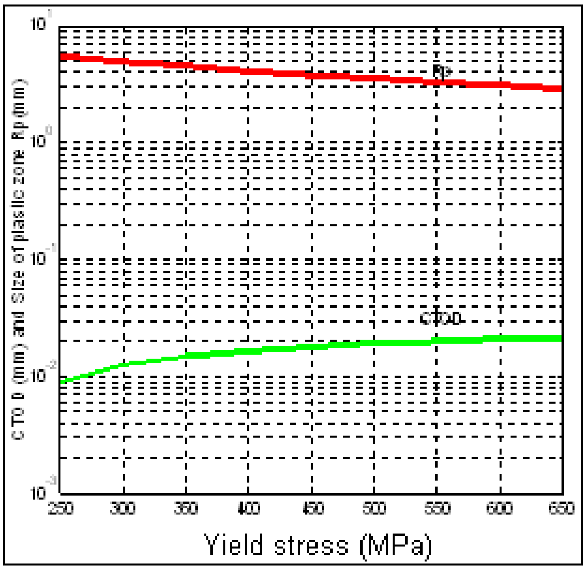

Fig. 11: CTOD and size of plastic zone (Rp), function of yield stress

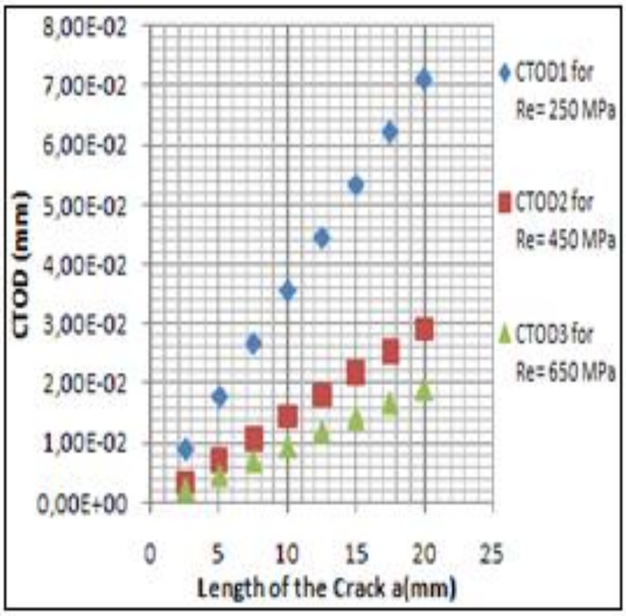

Fig. 13: CTOD function of length of crack for three value of yield stress (Re)

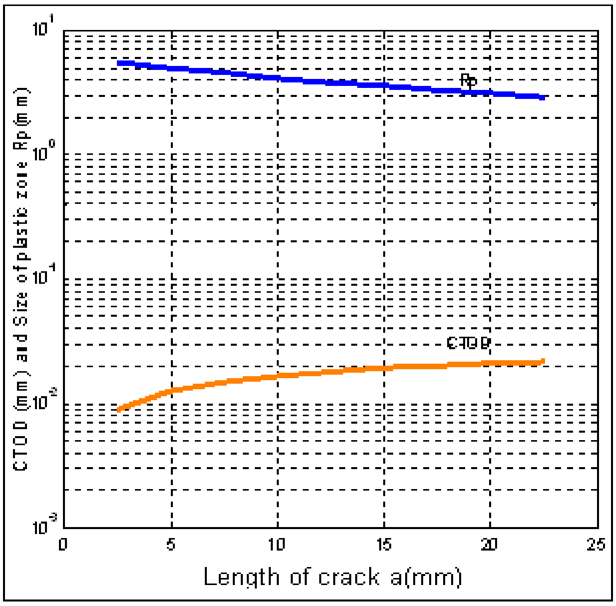

Fig. 12: CTOD and size of plastic zones (Rp) function of length of crack

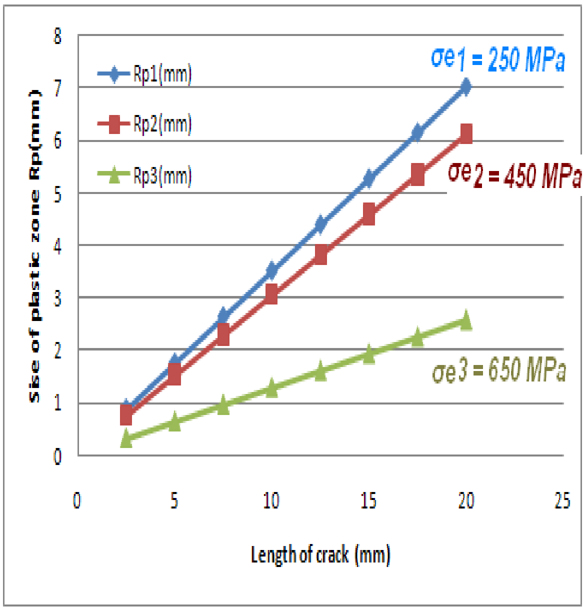

Fig. 14: size of plastic zones (Rp) function of length of crack

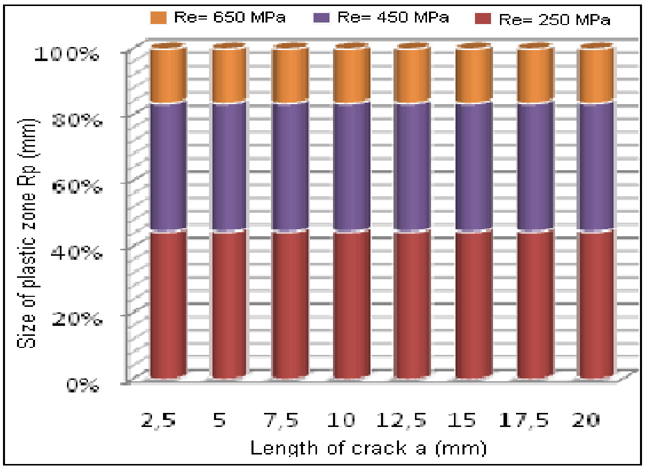

Fig. 15: size of plastic zones function of length of crack

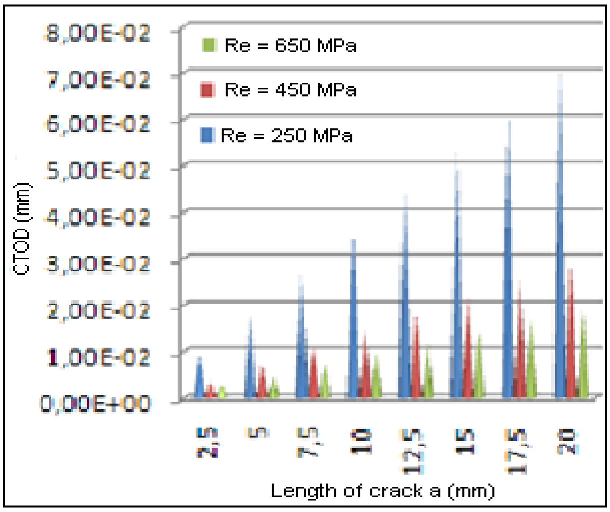

Fig. 16: CTOD function of length of crack

IV. Discussion

To obtain the best compromise between different properties to use an alloy, it is necessary to understand the evolution of these properties in an integrated manner throughout the production process [37]. The precision of the parts is related to the first functional tolerances tooling and a similar deformation or other validated in the case of plates subject of defects (cracks). To better improve the step of calculating, it has been a change in crack length, in order to determine the spacing elastic, plastic and any corresponding critical by comparing the results obtained in two main standards data. However in recent years aluminum alloy have emerged as attractive and viable commercial materials for automotive aerospace [38]. The results are recorded in Table 2 and 3. Single Edge Crack specimens recorded in Figure 3. The test was simulated in 2D and illustrated in Figures 4,5,6 and 7. The increased effort in terms of the evolution of plate movement is remarkable, which explains the greater the thickness of the plate increases the more you need extra effort mainly due to increasing resistance to thick walls and reinforced that requires that extra effort and load to be deformed. Values of the crack opening (CTOD), during loading are shown in the figures 8, 9, 11 and.16. It is easy to evaluate the deformation locally by the metal locally measuring its thickness. The graph in Figure 12 shows the variation of the distance function of elastic crack length, the evolution can reach 6.63 mm for the largest value of the crack 5 mm which corresponds to the center of the plate, is a tremendous value but reasonable mechanical point of view, giving a ductile appearance is a boon to the industry. We know that determining the tensile strength of brittle materials is usually done by a tensile test specimen on a rectangular section. The plastic state caused during the step of loading is then interact spacings plastics reviews (direct sum of the two spacings plastic and elastic). The spacing plastics vary depending on the lengths of the cracks. By analyzing the two curves in Figures 13 and 15, marked the first view is the continued decline gauge plastic during the evolution of the crack curves according to the two standards considered). The explanation of the decay curves of the spacings as a function of plastic crack lengths involves the phenomenon of hardening due mainly referred to hardening during the loading operation and the resulting gap in the plastic, it is a phenomenon of hardening mechanism favored by blocking the so-called dislocation, which are specific configurations of atoms found in all crystalline bodies. The failure criterion is associated with a critical stress distribution near the crack will be worth the stress intensity factor equal to the critical value, or ($K_I = K_{IC}$), other state mode I stress the immediate vicinity of the crack extension is well explained in the plastic Westergaard for distances mentioned we know that during their openings due to loading, lamination crack tip (crack tip) occurs in parallel (see Figure 4 and 5), this area is characterized by its laminate beam called lamination and is calculated by Von Mises and those of Rice. However, the development of critical distances based on crack lengths (Figure 14) is due to the sum of two types of distances, or the sum of the ductility and strength, these gauges are also critical the step preceding the propagation of the crack. To account for the physical process of crack propagation evoked, McClintock proposed that the crack is due to the accumulation of damage in an area around the crack tip to the sudden break. The size of this area of activity is taken as a fraction of the cyclic plastic zone. The numerical method allows us to describe the behavior of a structure to the point of resistance is therefore the finite element method. In our case, it is a calculation program for aluminum alloy (2024-T3) isotropic elastic behavior in a state of plane stress with the software Castem2001. The program allows us to obtain the dimensions of the plastic zone, and the distance to the crack tip element on which the finite element gives the amplitude of the equivalent strain after a load operation. These deformations are recorded at different amplitudes in figures 5 and 7 in parallel induce Von Mises stresses in the same figures. The purpose of the mesh is geometrically discretizing the field of analysis so as to associate a further geometrical formulation. Weibull speculated known as the weakest link, whereby a solid volume V consists of the juxtaposition of these N samples rupture of the weakest severing the entire solid. Visually spacings cracks

(CTOD) are remarkable As the amplitudes of the deformations are important (10 to 50 seconds), and at the tip of the crack can clearly see the plasticized zone having residual stress due the gaps, with sharp shapes of butterflies along the y axis. The other two curves which register the constraints according to axes X (SMXX) and Y (SMYY). The method of simulation is made by the energy method G-Θ, with full resolution J.

V. CONCLUSION

This work presents an interesting approach to modeling and calculation of spacing of cracks in a plate in aluminum alloy. The behavior model G-theta isotropic hardening was used. Considering the lateral fissure of the plate, we have successfully calculated key parameters in fracture mechanics which are the distances elastic, plastic and critical. By completing the simulation of the plate cracked before and after applying the load is concentrated together with stresses and strains recorded. For the designer and producer of such default is driven by all means.

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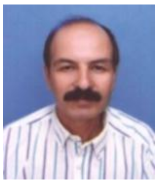

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