FINITE ELEMENT ANALYSIS OF THE EFFECT OF MICRO-CRACK ON THE PLASTIC STRAIN AHEAD OF MAIN CRACK IN ALUMINIUM ALLOY

B. Bachir Bouiadjra, M. Elmeguenni, M. Belhouari, M. Benguediab and B. Serier

LMPM, Université Djilali Liabes de Sidi Bel Abbés, Faculté des Sciences de l’Ingénieur, Département de Génie Mécanique. BP 98 Cité Ben M’Hidi Sidi Bel Abbés 22000, Algérie. Tél.: 0021348544100. Fax : 0021348544100 Email : bachirbou@yahoo.fr

1. Introduction

It is commonly understood that fracture behavior of ductile material depends on the plastic deformation created ahead of the crack tip. In understanding of fatigue properties of metallic alloys, out most important is the precise characterization of the plastic deformation of the materials in the vicinity of the crack tip. The plastic behavior near the tip of stationary crack in engineering materials has been intensively studied using classical plasticity theory based on the Von-Mises yield criterion and the associative flow rules [1-3]. It was shown that the size and the shape of the plastic zone affect the crack growth behavior. On the other hand, the fatigue process and its mechanism are largely influenced by the presence of material inhomogeneities that are inherent to the materials such as microcracks.

A study of interaction between main cracks and micro defects in thin plate is important in providing a good understanding of mechanical behavior of structures with defects and is helpful to the material and structural design. This type of problems has been studied by many authors [4-6]. Notice that most authors considered an elastic behavior of materials. When cracks are analyzed, the behavior of the material ahead of the crack tip is considered isotropic, i.e., plastic deformation occurs identically in all directions and there are no preferred directions for the plastic deformation.

In this case, the plastic deformation can be mathematically formulated with models of crack tip plasticity. This situation significantly differs when the crack tip's near a micro-crack, the plastic zone ahead of the crack tip will be affected by the presence of the microdefects.

The aim of this study is to analyze the effect of presence of micro-crack on the shape and size of the plastic zone ahead of main crack tip using the finite element method for the case of small scale plasticity. Four configurations related to the position of the micro defect are analysed:

- Micro-crack in the prolongation of the crack tip.
- Micro-crack parallel to the main crack.

2. Geometrical and Finite element models

Let us consider a rectangular thin plate in Aluminum alloy 2024 T (Fig.1), with high H and width W, the ratio H / W is equal to 0.5. The plate is subjected to a tensile load with amplitude $\sigma = 20$ MPa. An edge crack with length a is supposed to exist at the centre of the plate. The ratio $W / a$ is 0.2. A micro-crack is supposed to exist near the crack tip having length $200 \mu m$. The distance between the crack tip and the micro-crack is d. The ratio $d/a$ is varied in order to analyze the effect of the distance d on the size and the shape of the plastic zone ahead of the crack tip. The elastic properties of the material of the plate (Aluminum alloy 2024 T) are: Young Modulus $E_1 = 72000$ MPa, Poisson’s ratio $\nu = 0.3$ and Yield stress $\sigma_y = 350$ MPa.

Finite element analysis of configurations of figure 1 is done using the finite element code FRANC2D/L developed at Cornell University [7], which elastic-plastic performance was validated [8]. The structure is idealized by quadrilateral eight nodes element. Special quarter point node elements are implemented around the crack tip. Figure 2 show typical mesh model of the global structure and near the micro-crack and the main crack tips. The Von-Mises criterion is used to determine whether the stress in the materials causes plastic flow. Incremental plasticity theory is introduced to model the material non-linearity. The Newton-Raphson iterative method is used as approach for resolving non-linear finite element equations.

3. Analysis and results

In all calculations realized in this study, the contour of the plastic zone at the main crack tip with presence of the micro-crack is compared to the case without micro-crack. It can be noted in all results presented in this paper that when the effect of micro-crack is nonexistent the plastic zone at the crack tip has a regular form which is in concordance
with literature [3]. The ratio of the plastic zone radius \( r_p \) to the crack length \( a \) (\( r_p/a \)) is about 1.2 \%, what allow us to deduce that it is a case of confined plasticity. In what follows the effect of the presence of microcrack near the crack tip on the size and the shape of the plastic zone is analysed for the four configurations of the positions of the micro-crack shown previously.

3.1 Micro-crack located in the prolongation of the crack

In this paragraph, the effect of a micro-crack located in the axis of the principal crack on the shape and the size of the plastic zone ahead of the main crack tip is analyzed. The distance between the two crack tips is equal to \((d)\). Four values of the ratio \((d/a)\) were chosen equal to : 1.25\%; 5\%; 8.75\% and 12.5\%. Figure 3 presents the contour of the plastic zone ahead of the main crack tip for \(d/a=1.25\%\), compared with the case where the micro-crack does not exist. It is noticed that the plasticized zone is divided into two parts located in both sides of the micro-crack. The plastic zone ahead of the main crack tip has a lower size than the second zone (located ahead of the micro-crack.). This is due to the fact that the stresses on the top and the bottom of the micro-crack are weak what causes the elimination of plastic strain in these zones. This effect will involve the division of the plastic zone ahead of the main crack tip.

When the micro-crack is located at a relative distance \(d/a=5\%\) (Fig. 4), it is also noted a presence of two plasticized zones, one of low size ahead of the micro-crack and the second ahead of the main crack with more significant size. The tendency is thus reversed compared to the preceding case \((d/a=1.25\%)\). The micro-crack being further away from the main crack, its effect on the main crack plastic zone is not very significant; but since the micro-crack is located in a high stress region, there is plasticization ahead of the micro-crack. There are thus two plastic zones, one specific to the main crack and the second to the micro-crack. It is obvious that the size of this second plastic zone will decrease as the micro-crack move away the main crack.

Results presented on figure 5 confirm those of preceding figure. Indeed, figure 5 presents the contour of the plastic zone for \(d/a = 8.75\%\). It can be seen that the second plastic zone disappears because the micro-crack left the region of high stress field and the intensities of stresses around its tips did not produce plastic strains. On the other hand, it is interesting to see in this last figure that the width of the plastic zone is less important compared with the case without micro-crack, the difference is about 30\%. The relaxation of the stresses far for the micro-crack leads to a reduction of the plastic strain near the tip of the main crack. For a ratio of distance \(d/a = 12\%\) (Fig. 6), the effect of the micro-crack disappears completely and the plastic zone at the main crack tip will regain its classical shape and its size is equal to the case without presence of the micro-crack.
3.2 Micro-crack parallel to the main crack

With an aim of analyzing this effect, one supposes the existence of a micro-crack with same length and parallel the main crack. The distance between the two cracks is d. One considered four relative distances: \(d/a = 1.875\%\); 5\% and 8.75\%. Figure 7 presents the contour of the plastic zone for \(d/a = 1.875\%\); compared with the case without presence of the micro-crack. It is shown that the plastic zone is divided into two parts and the part located ahead of the micro-crack has a more significant size. The micro-defect being very close to the main crack tip, an effect similar to that of a micro-crack located on the prolongation of the main is observed. The stress relaxation in the top and the lower region of the micro-crack involves this phenomenon.

Figure 7: Contour of plastic zone for configuration b (d/a =1.875\%).

Figure 8 : Contour of plastic zone for configuration b (d/a =5\%).

Figure 8 presents the contour of the plastic zone for \(d/a = 5\%\). It should be noted that the plastic zone located ahead of the micro-crack has lower size. When the ratio \(d/a\) is equal to 8.75\% (Fig. 9), the second plastic zone disappears and the effect of the presence of the micro-crack on the plastic strain ahead of the main crack is less significant. The plastic zone has less significant high, but its width remains more important. The region of high stresses near the micro-crack increases the plastic stress ahead of the main crack.

Figure 9: Contour of plastic zone for configuration b (d/a =8.75\%).

4. Conclusions

This study has been made in order to estimate by the finite element method the effect of presence of a micro-crack on the size and the shape of the plastic zone ahead of main crack for small scale plasticity. The obtained results allow us to deduce the following conclusions:

- If the micro-crack is in the very close vicinity of the main crack, its presence provoke a division of the plastic zone in two parts.
- If the micro-crack is relatively close to the main crack, its presence in height stress field enables it to have its specific plastic zone separately.
- The effect of the micro-crack disappears when the relative distance between the two cracks is greater than 10%.

References


