

# Fatigue Crack Initiation of Al-Alloys “Effect of Heat Treatment Condition”

M. Benachour, N. Benachour, M. Benguediab

**Abstract**—In this investigation an empirical study was made on fatigue crack initiation on 7075 T6 and 7075 T71 Al-alloys under constant amplitude loading. In initiation stage, local strain approach at the notch was applied. Single Edge Notch Tensile specimen with semi circular notch is used. Based on experimental results, effect of mean stress, is highlights on fatigue initiation life. Results show that fatigue life initiation is affected by notch geometry and mean stress.

**Keywords**—Fatigue crack initiation, Al-Alloy, mean stress, heat treatment state.

## I. INTRODUCTION

FATIGUE life of a structure is divided into three stages [1]: fatigue crack initiation, stable crack propagation and unstable crack propagation. Stress concentration will be produced in several geometrical discontinuities as a result of external force and depend of notch radius. The stresses are generally higher than the nominal values. Fatigue crack initiation life has been estimated by many authors [2]-[4] when different approaches will be used, which is based on nominal stresses, stress concentration factor and local stress-strain concepts. Others researchers employed the equivalent strain-energy density method to predict fatigue crack initiation [5]-[7]. In these works it was be assumed that crack propagation part of fatigue life is small comparatively to the fatigue initiation life.

Fatigue life of materials and structures depends on several parameters. In initiation stage, fatigue life is linked strongly to metallurgical (thermal heating), geometrical and loading parameters. The Al-alloy 7075 in the peak aged heat treatment condition T6xxx or heat-treated and then over-aged/stabilized T7xxx (subsequently referred to as T6 or T7) has been widely used for structural applications in many aircraft designed in the 50's and 60's. Effect of heat treatment (precipitation hardening) on fatigue life of two Al-alloys (2024) and (7075) was studied by Al-Khazraji [8]. The alloy (2024) is hardening by natural aging, while the artificial aging is used to hardening the alloy (7075). In this investigation, notched and un-notched specimens are used to perform fatigue tests with different type

of heat treatment when fatigue life equation was estimated based on experimental data.

Investigation of aluminum alloy 2024 with two temper situations (T3 and T62) was conducted by Benachour et al. [9]. It was found that aluminum alloy 2024 T62 present a good fatigue crack growth resistance at high stress intensity factor comparatively to aluminum alloy 2024 T3.

Important loading parameter is mean stress characterized by variation of amplitude loading or stress ratio, the latest parameter is studied by several researchers, principally in stable crack propagations on some aluminum alloys [10]-[12]. Effect of stress on the proportion of the total life occupied by initiation and propagation of the crack is discussed by Pearson [13].

Various equations to account for the mean stress dependence of crack propagation data have been described by Mann [14]. They have been fitted to data from the Al-alloys 7075-T6, 2024-T3 and 6082-T6. The effects of the stress ratio, R, on fatigue crack growth rate of 7075 T651 Al-alloy were investigated by Zhao et al. [15] and significant stress ratio, R, was identified. Results of positive values of stress ratio effects, in increasing case, shown a decreasing of number of cycles to initiate a fatigue crack while the alternating stress is kept constant [16].

In recent investigation of Ranganathan et al [17], crack initiation phase has been considered in the estimation of total fatigue life when short crack growth approach was used. In this paper, mean stress and heat treatment state on fatigue initiation life were studied from the SENT specimen with semi circular notch on Aluminum alloy 7075.

## II. MODEL OF FATIGUE CRACK INITIATION: LOCAL STRAIN APPROACH

Fatigue resistance of metals can be characterized by a strain-life curve. Tugel initially provided the strain-life based fatigue crack initiation module [18]. Strain-life based crack initiation analysis method to predict crack initiation life is incorporated in AFGROW code [19]. In fatigue case and at the notch tip, local strains are obtained by using the Neuber's rule or Glinka [20] expressed in following form:

$$\frac{(K_f \cdot \Delta \sigma_a)^2}{4E} = \frac{\Delta \sigma \cdot \Delta \epsilon}{2} \quad (1)$$

M. Benachour is with the university of Tlemcen, IS2M Laboratory of Tlemcen, Faculty of Technology, BP 230, Tlemcen, Algeria (phone: +213 43 28 56 86; fax: +213 43 28 56 85; e-mail: bmf\_12002@yahoo.fr).

N. Benachour is with the Physics Department, University of Tlemcen, Faculty of Sciences, IS2M Laboratory, Algeria, (e-mail: nbenachour2005@yahoo.fr).

M. Benguediab is with Sidi Bel Abbes University. He is now with the Department of Mechanical Engineering (e-mail: benguediab\_m@yahoo.fr).

where “ $\sigma_a$ ” is the applied stress and “ $\sigma$ ” and “ $\varepsilon$ ” are the resulting local stress and strain values corrected for the notch effect.

The fatigue notch factor, ( $K_f$ ), is essentially the  $K_t$  value corrected to account for the notch sensitivity for the given material [21]. It is determined as follows:

$$K_f = 1.0 + \left( \frac{K_t - 1.0}{1.0 + (\alpha/r)} \right) \quad (2)$$

where “ $\alpha$ ” is an empirically determined material constant [22] and  $r$  is the notch root radius.

In Glinka’s approach the local strains and stresses should represent energy equivalence as compared the remote loading conditions, leading to the following equation:

$$\frac{(K_f \cdot \Delta\sigma_a)^2}{2E} = \frac{\Delta\sigma^2}{4E} + \frac{\Delta\sigma}{n'+1} \left( \frac{\Delta\sigma}{2K'} \right)^{\frac{1}{n'}} \quad (3)$$

In this equation  $K'$  and  $n'$  correspond to the material’s cyclic hardening law.

The local strains were determined by coupling (1) and (3), given local strain range in function of local stress range named cyclic stress-strain (4).

$$\frac{\Delta\varepsilon}{2} = \frac{\Delta\sigma}{2E} \left( \frac{\Delta\sigma}{2K'} \right)^{\frac{1}{n'}} \quad (4)$$

The relationship between total strain amplitude,  $\Delta\varepsilon/2$  and life to failure,  $2N_f$ , can be expressed in the form [23]:

$$\frac{\Delta\varepsilon}{2} = \frac{\sigma'_f}{2E} (2N_f)^b + \varepsilon'_f (2N_f)^c \quad (5)$$

where “ $\sigma'_f$ ” is the fatigue strength coefficient; “ $b$ ” is the fatigue strength exponent, “ $\varepsilon'_f$ ” is the fatigue ductility, “ $c$ ” is the fatigue ductility exponent.

### III. MATERIAL PROPERTIES AND SPECIMEN GEOMETRY

The material used in this study is Al-alloys 7075 in two temper situation namely T6 and T73. SENT specimens with semicircular notch are subjected to simulated tensile fatigue tests in constant amplitude loading (Fig. 1). The basic mechanical properties for studied aluminum alloys are given in Table I.

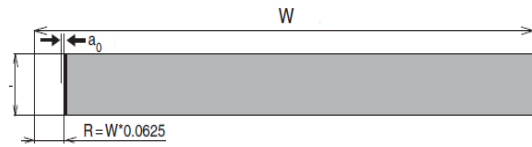


Fig. 1 SENT specimen with semi-circular edge notch

TABLE I  
 MECHANICAL PROPERTIES OF 7075 AL-ALLOY

Material	$\sigma_{0.2}$ (MPa)	$K_C$ (MPa.m <sup>0.5</sup> )	$K_{IC}$ (MPa.m <sup>0.5</sup> )	E (Gpa)	$\nu$
T6	517.11	59.39	29.67	71.70	0.33
T73	413.68	61.54	30.77	71.71	0.33

Basic cyclic strain-life properties used in fatigue crack initiation analysis for studied material of the notched specimen are shown in Table II.

TABLE II  
 CYCLIC STRAIN LIFE PROPERTIES OF 7075 AL-ALLOY

	$\sigma'_f$	$\varepsilon'_f$	$b$	$c$	$K_f$	$K'$	$n'$
T6	1316.9	0.19	-0.126	-0.52	$5.08 \times 10^{-4}$	965.26	0.1
T73	799.79	0.26	-0.098	-0.73	$0.5 \times 10^{-4}$	510.21	0.03

### IV. RESULTS AND DISCUSSION

SENT specimen with semi-circular notch was subjected to remote uniform tensile stress with variation of mean stress. Fig. 2 shown mean stress effect on fatigue initiation life. An increasing in mean stress increase the fatigue initiation life for both studied materials. This increasing is due to the diminution of amplitude loading range,  $\Delta\sigma$ , when maximum amplitude is kept constant. Initiation fatigue life  $N_i$  is interpolated by exponential equation at 97% (see equations 6 and 7). It was shown that Al-alloy 7075 at temper situation T6 present high resistance to crack initiation. This difference was affected by variation in mechanical properties. For same mean stress, the ratio of fatigue life initiation is about 6.8 for low mean stress. Contrarily, for high mean stress the ratio decrease at 2.6.

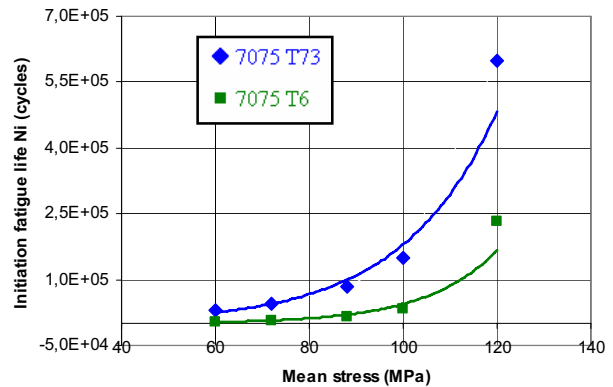


Fig. 2 Effect of mean stress on fatigue initiation life

$$7075 \text{ T6 } N_i = 1279.4 e^{0.0495 \sigma_m} \quad (6)$$

$$7075 \text{ T73 } N_i = 62.27 e^{0.0658 \sigma_m} \quad (7)$$

Fig. 3 indicates the difference in fatigue under temper effect. Results shown that Al-alloy 7075 in heated state T73 present a good fatigue crack growth resistance comparatively to the heated state T6. Additionally, this result shows also that initiation stage of crack is dominant compared to the fatigue crack growth stage. For example for 7075 T6 Al-alloy, the initiation life for is about  $8.2 \times 10^{-4}$  cycles and the fatigue crack growth life  $1.8 \times 10^{-4}$  cycles. Then the fatigue initiation life present seven times life of crack propagation.

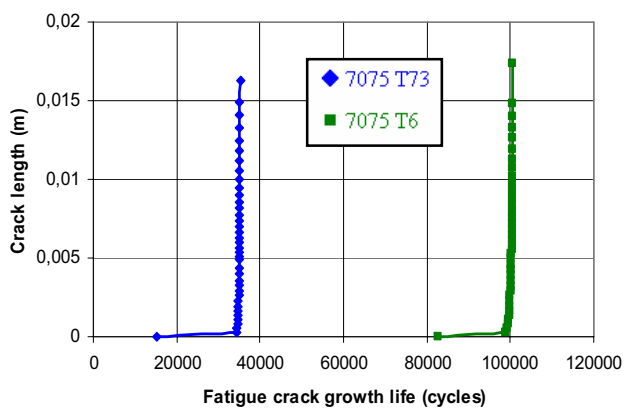


Fig. 3 Effect of heated state on total fatigue life (Ni+Np)

#### V. CONCLUSION

Fatigue crack initiation of 7075 al-alloy in two heated state (T6 and T73) on SENT specimen with semi-circular notch was investigated in this study. The main conclusions are cited below:

- \* Fatigue life is related to crack initiation. Crack initiation is related to applied mean stress, stress concentrations and material properties.
- \* An increasing in mean stress, increase total fatigue life.
- \* Initiation stage of crack is dominant compared to the fatigue crack growth stage.

#### REFERENCES

- [1] Glinka G. "Residual stress in fatigue and fracture: Theoretical analyses and experiments". In Niku-Lari A., Editor, *Advances in Surfaces Treatments*, pp 413-454. Pergamon Press, 1987. Residual stresses, volume 4.
- [2] Glinka, G., "A Notch Stress-strain Analysis Approach to Fracture Crack Growth". *Engineering Fracture Mechanics*, Vol. 21, No. 2, pp. 245-261, 1985.
- [3] Socie, D. F., "Fatigue-life Prediction Using Local Stress-Strain Concept". *Experimental Mechanics*, Vol. 17, pp. 50-56, 1977.
- [4] Truchon, M., "Application of Low-Cycle Fatigue Test Results to Crack Initiation from Notches, Low-Cycle Fatigue and Life Prediction". ASTM STP 770, C. Amzallag, B. N. Leis, and P. Rabbe, (Eds.), American Society for Testing and Materials, pp.254-268, 1982.
- [5] Zheng X. "On some basic problems of fatigue research in engineering", *Int. J. Fatigue* 2001; 23:751-66.

- [6] Khan, Z., Rauf, A. and Younas, M., Prediction of fatigue crack propagation life in notched Members under variable amplitude loading," *Journal of Materials Engineering and Performance*, Vol. 6, No. 3, pp. 365-373, 1997.
- [7] Zheng M, Niemi E, Zheng X. "An energetic approach for predict fatigue crack initiation life of LY 12 CZ aluminum and 16 Mn steel". *Theor Appl Fract Mech* 1997; 26:23-8.
- [8] Ahmed. N. Al-Khazraji. "Effect of heat treatment on fatigue life of aluminum alloys 2024 and 7075". *Eng. & Tech. Journal*, Vol.28, No.22, 2010.
- [9] M. Benachour, M. Bengueidab, A. Hadjoui, N. Benachour. "Fatigue crack growth of different aluminum alloy 2024". 17th European Conference of Fracture: ECF 17. Multilevel Approach to Fracture of Materials, Component and Structures, 2-5 September 2008, Bron, Czech. Book edited by Jaroslav Pokluda and Petr Lucáš, Pavel Šandera, Ivo Dlouhý. VUTUM, Brno – Czech, pp 1047-1052.
- [10] R.T. Holt, M.D. Raizenne, W. Wallace, D.L. Duquesnay. "RRA Heat Treatment of Large Al 7075-T6 Components". RTO AVT Workshop on "New Metallic Materials for the Structure of Aging Aircraft", Corfu, Greece, 19-20 April 1999.
- [11] F.J. McMaster, D.J. Smith, *International Journal of Fatigue* 23, S93-S101, (2001)
- [12] C.A. Rodopoulos, J. H. Choi, E.R. de los Rios, J.R. Yates. "Stress ratio and the fatigue damage map—Part II: The 2024-T351 aluminium alloy". *International Journal of Fatigue* 26, 2004, pp 747-752.
- [13] S. Pearson. "Initiation of fatigue crack in commercial aluminium alloys and the subsequent propagation of very short cracks". *Engineering Fracture Mechanics* 1975, Vol. 7, pp. 235-247.
- [14] T. Mann. "The influence of mean stress on fatigue crack propagation in aluminium alloys". *International Journal of Fatigue* 29(8), 2007, pp 1393-1401.
- [15] T. Zhao, J. Zhang, Y. Jiang. "A study of fatigue crack growth of 7075-T651 aluminum alloy". *International Journal of Fatigue* 30, 2008, pp 1169-1180.
- [16] R. Fuczak. "Effects of R-ratio on crack initiation at external discontinuities in autofretted cylinders". *Experimental Mechanics* 9, 1984, pp 122-128.
- [17] N. Ranganathan, H. Aldroo, F. Lacroix, F. Chalon, R. Leroy, A. Tougui. "Fatigue crack initiation at a notch". *International Journal of Fatigue* 33, 2011, pp 492-499.
- [18] Tuegel, E., "Strain-life crack initiation life software, provided by analytical processes and engineered solutions (AP/ES)", Inc., 1996.
- [19] Harter, J.A., "AFGROW users guide and technical manual: AFGROW for Windows 2K/XP". Version 4.0011.14, Air Force Research Laboratory.
- [20] Neuber, H., "Theory of Stress Concentration for Shear-Strained Prismatical Bodies with Arbitrary Nonlinear Stress-Strain Law". *Trans. ASME, Journal of Applied Mechanics*, 1960. pp. 544-550.
- [21] Peterson, R.E., "Stress Concentration Factors". John Wiley and Sons, 1974.
- [22] Hall, L.H. et al., "Fracture and Fatigue of Surface Flaws and Flaws Originating at Fastener Holes". Volume 1, AFFDL-TR-74-47, 1973.
- [23] Coffin, L.F., "A study of effects of cyclic thermal stresses on a ductile metal". *Transactions of the ASME*, 76, 1954, pp. 931-950, 1954.