Fatigue Crack Growth of Different Aluminum Alloy 2024

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Key words: Fatigue, aluminum alloys 2024, load ratio, heat treatment.

Abstract: The choice of a material for a given construction requires a major knowledge on its behavior with respect to the type of loading applied and the state of its use. Various parameters can influenced the fatigue behavior with knowing the parameters related to material or the parameters related to the operating conditions. This work presents the effect of the load ratio R on the behavior of fatigue crack growth. The effect of the heat treatment or the state of material on the propagation is examined. The study is undertaken on the SENT specimen out of aluminum 2024 alloy (T3, T351, T6...) using AFGROW code. The influence of the state of material proves to be significant considering the changes of the physical and mechanical characteristics on tenacity, the threshold of non cracking, the limit of endurance, the microstructure, etc. This study is undertaken under constant amplitude loading. The results show the influence of the two parameters on the shift of the curves of the fatigue life according to the propagated length.

Introduction

Aluminium alloys are the second most widely used metallic materials after steels. Aluminum and its alloys are being used successfully in a wide range of applications, from packaging to aerospace industries. Due to their good mechanical properties and low densities, these alloys have an edge over other conventional structural materials. 2024 variant alloys, such as higher purity 2124 and 2324 and 2024 in different tempered situations (T3, T351, T81, T62. etc) with improvements in strength and other specific characteristics, have also found application in critical aircraft structures. The 2024 aluminum alloy remains as an important aircraft structural material due to its extremely good damage tolerance and high resistance to fatigue crack propagation in T3 aged condition [1].

Zhang et *al* [2] studied the effect of shock waves excited by laser on aluminum alloy 2024 in T62 tempered condition. The ultimate tensile strength, surface hardness, elastic modulus and Poisson ratio increase on theirs effects. The relations between these factors and the fatigue life of the specimens are investigated. The fatigue tests results show that Laser Shocked Processing can increase the fatigue life and decrease the fatigue crack growth rate of 2024-T62 aluminum alloy [3].

Kuo et *al* [4] investigates the relationship between fracture behavior and thermomechanical effects in AA2024 aluminum alloy of T3 and T81 temper designations.

In Golden work [5], a comparative study for two aluminum alloy 2024 T3 and 2524 T3 are presented when the resistance to the onset of multi-site damage is investigated in thin sheet plate. Aluminum alloy offer improved performance with respect to the onset of multi-site damage.

Genevois et *al* [6] shown that the tensile properties of the various regions of the 2024 T351 and 2024 T6 welds are very heterogeneous and essentially controlled by the state of precipitation. The 2024 T6 base material is stronger than the 2024 T351 alloy, leading to a more pronounced strain localisation during transverse tensile tests and a lower overall ductility.

A significant number of authors [7-11] are studied the behaviour of 2024 T351 aluminum alloy when the effect of several factors highlighted the fatigue behaviour of this alloy 2024 T351 (effect of load, residual stresses, environment, corrosion... etc.) [12-15].The aim of this paper is to present the effect of different tempered situations on fatigue crack growth of aluminum alloy 2024 and the loading ratio.

Fatigue crack growth of SENT specimen

Material and specimens

The material used in this study is the aluminium alloy 2024 in three tempered situations such as T3 solution heat-treated, cold worked, and naturally aged to a substantially stable condition, T62 Solution heat-treated from annealed and T351 solution heat-treated and naturally aged to a substantially stable condition. L-T orientation is subjected to numerical fatigue tests. The basic mechanical properties for Aluminum alloys 2024 are given in Table 1. Numerical fatigue crack growth in mode I used SENT specimen single edge through crack (figure 1).

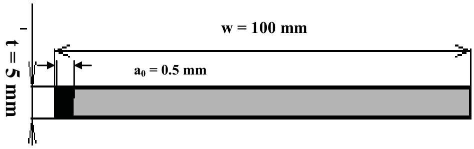

Fig. 1 SENT specimen with single edge through crack

Table 1. Mechanical properties for different aluminum alloy 2024 (AFGROW Data Base)

Aluminum alloy 2024	$\sigma_{0.2}$ (MPa)	K_{IC} $MPa\sqrt{m}$	K_C $MPa\sqrt{m}$	E (GPa)
T3	365.422	36.262	72.524	73.084
T351	372.317	37.361	74.722	73.084
T62	399.896	39.558	79.116	73.084

The stress intensity factor for the studied specimen SENT specimen with single edge through crack implemented in AFGROW code is written bellow:

$$\Delta K = \sigma\sqrt{\pi a}.\beta \tag{1}$$

when β is the geometry function.

Fatigue crack growth model

AFGROW code developed by NASA [16] is used for simulation of fatigue crack growth with and without residual stress. Many models for fatigue crack growth are implemented. The interest model is NASGRO model when totality of fatigue crack growth curves is considered.

NASGRO model are expressed bellow:

$$\frac{da}{dN} = C\left[\left(\frac{1-f}{1-R}\right)\Delta K\right]^n \frac{\left(1-\frac{\Delta K_{th}}{\Delta K}\right)^p}{\left(1-\frac{K_{\max}}{K_{crit}}\right)^q} \tag{2}$$

f present the contribution of crack closure and the parameters C, n, p, q were determined experimentally and ΔK_{th} is the crack propagation threshold value of the stress-intensity factor range. For constant amplitude loading, the function f determined by Newman [17] can be written as:

$$f = \frac{K_{op}}{K_{max}} = \begin{cases} \max\left(R, A_0 + A_1 R + A_2 R^2 + A_3 R^3\right) & R \geq 0 \\ A_0 + A_1 R & -2 \leq R < 0 \\ A_0 - 2A_1 & R < -2 \end{cases} \tag{3}$$

where the polynomial coefficients are given by:

$$\begin{aligned} A_0 &= \left(0.825 - 0.34\alpha + 0.05\alpha^2\right)\left[\cos\left(\frac{\pi}{2}\sigma_{max}/\sigma_0\right)\right]^{\frac{1}{\alpha}} \\ A_1 &= (0.415 - 0.071\alpha)\sigma_{max}/\sigma_0 \\ A_2 &= 1 - A_0 - A_1 - A_3 \\ A_3 &= 2A_0 + A_1 - 1 \end{aligned} \tag{4}$$

α is plane stress/strain constraint factor (α=1 for plane stress and α= 3 for plane strain).

Results & discussions

Effect of load ratio

SENT specimens in L-T orientation are subjected to a constant loading with various load ratios. The K_{max} fracture criteria are adopted for the limit of crack growth. Figures 2, 3 and 4 showed the effect of load ratio on fatigue crack growth rate for three tempered 2024 aluminum alloy and illustrates a general increase in da/dN with R for a given ΔK. An important effect of R has been observed clearly for this material at high ΔK. Theses results are in agreement with the results of Srivastava and Garg [18]. A weak reduction in the fatigue crack growth rate is announced to the low values of the factor stress intensity factor with the variation of load ratio R. At high stress, the fatigue crack growth is important.

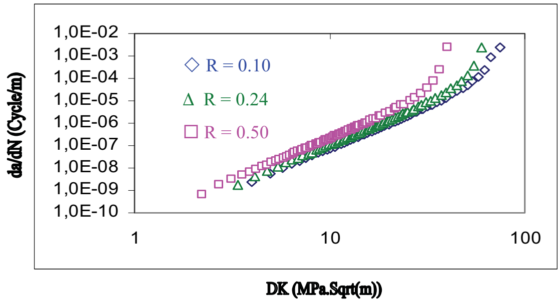

Fig. 2 Effect of load ratio on fatigue crack growth rate for 2024 T62

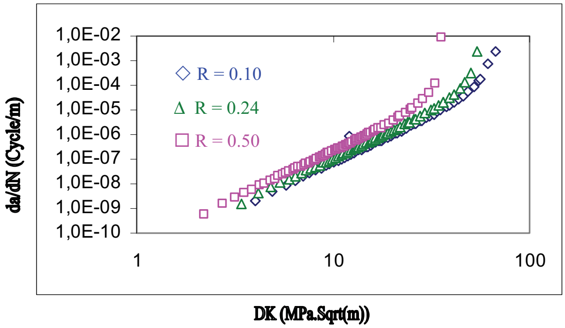

Fig. 3 Effect of load ratio on fatigue crack growth rate for 2024 T3

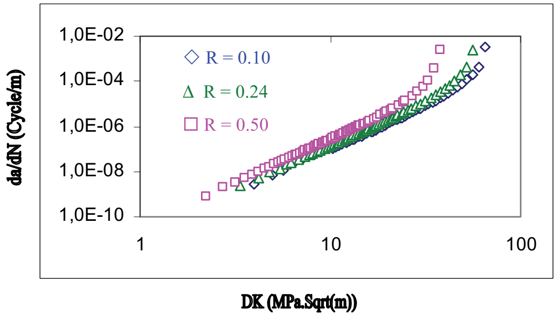

Fig. 4 Effect of load ratio on fatigue crack growth rate for 2024 T351

Effect of heat treatment (Tempered situations)

The figures 5 and 6 present the variation of fatigue life for two load ratio (R=0.1 and R=0.5) in three tempered case under the same load in L-T orientation. These figures showed the interaction between T351 and T3 temper. For R=0.5, the fatigue life for 2024 T3 and 2024 T62 is very important comparatively to the fatigue life at R=0.1.

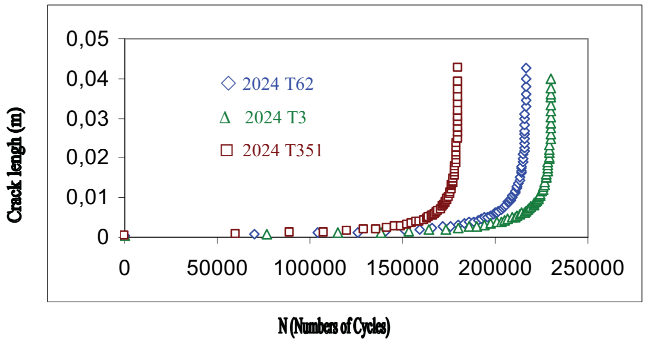

Fig. 5 Fatigue life for R=0.1 at three temper

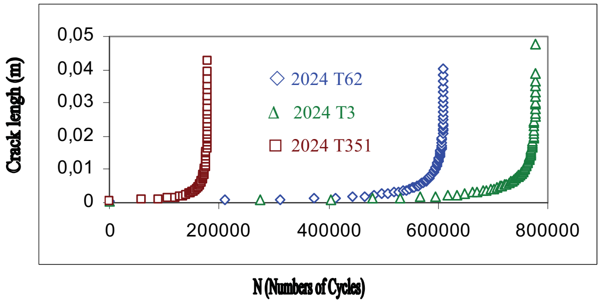

Fig. 6 Fatigue life for R=0.5 at three temper

The effect of condition temper for aluminum alloy on fatigue crack growth rate is presented in figure 7. The aluminum 2024 T62 present a good resistance to the fatigue comparatively to the aluminum alloy 2024 T351. The difference between 2024 T3 and 2024 T62 for the fatigue crack growth in Paris region is very weak. At the same stress intensity factor, ΔK≈10 MPa.Sqrt(m), the fatigue crack growth rate is import for 2024 T351 (see table 2).
The comparison of the curves of propagation in fracture points shows that the stress intensity factor for the 2024 T62 is three times more than the 2024 T351 i.e. that the crack growth rate is three times less(figure 7).

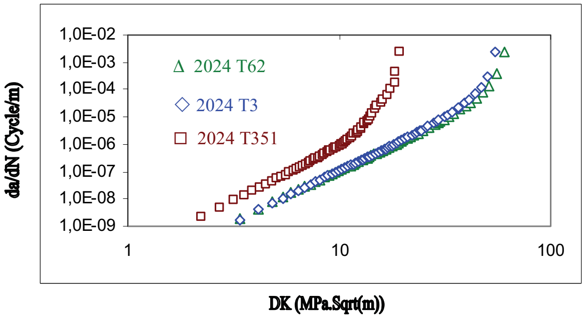

Fig. 7 Fatigue crack growth rate for aluminum 2024
at three tempered situations (R=0.24)

Table 2 Fatigue crack growth rate at same stress intensity factor

Aluminum alloy 2024	ΔK $MPa\sqrt{m}$	da/dN x 10^{-7} (Cycle/m)
T3	10.28	1.189
T351	10.04	1.395
T62	10.33	1.222

Conclusion

Paper presents the results of simulation of fatigue crack growth using AFGROW code. The effect of loading ratio and heat treatment (tempered situation) for aluminum alloy 2024 are investigated. The results showed that the aluminum 2024 T3 and 2024 T62 present the same resistance. Comparatively to the aluminum alloy 2024 T351, the aluminum 2024 T62 present a high resistance. The fatigue life is affected by temper condition.

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