PAPER REF: 4743

INFLUENCE OF COMPOSITE PATCH REPAIR ON FATIGUE CRACK GROWTH IN 6061 AL-ALLOY

M. Benachour[1(*)], N. Benachour[1,2], M. Benguediab[3]

[1]IS2M Laboratory, Mechanical Engineering, Faculty of Technology, University of Tlemcen, Tlemcen, Algeria
[2]Department of Physics, Faculty of Sciences, University of Tlemcen, Tlemcen, Algeria
[3]Mechanical Engineering, Faculty of Technology, University of Sidi Bel Abbes, Sidi Bel Abbes, Algeria
[(*)]*Email:* bmf_12002@yahoo.fr

ABSTRACT

In this work effects of composite patch repair were investigated in order to characterize the fatigue crack growth behavior of 6061-T6 and 6061-T651 Al-alloys plate with a single sided fiber reinforced composite patch. Using empirical analysis, Stress intensities factor were calculated when critical stress intensity factor are based on patched structure, from which the fatigue crack growth rates were evaluated using Nasgro model based on experimentally data. For the patched and un-patched plate, effect of different stress ratio on fatigue crack growth (FCG) was investigated. The results show that fatigue life was affected by tempered materials and stress ratio, and retardation of crack growth is found in the bonded repair.

Keywords: fatigue crack, composite patch repair, heated state, Al-alloys.

INTRODUCTION

Generally structures are subjected to cyclic loading during service which consequently leads to damage and creating of cracks. New technique developed by Australian researchers was used for reparation of aircraft structures (Christian, 1992), called composite patch repair, applied to reinforce the damaged structures and extend the service life of aging aircraft. Different grades of aluminum alloys were used with different heat treatments in order to provide good resistance for different damage. The types of 6000 alloy are among those, which have responded positively to modify ageing procedure involving, interrupted ageing. These alloy widely used of medium strength with major application as extrusion product and automotive body sheet. Alloy 6061 is one widely used alloy in the 6000 series with solution heated treated and artificially aged (T6, T651…). In the investigation of Chung et al. (2002) fatigue behavior of solid solution treated 6061 Al alloy fabricated by equal channel angular pressing process were evaluated. A remarkably large enhancement in fatigue life was recognized to occur in low and high cycle regimes after a single pass compared to a T6 treated commercial 6061 Al-alloy. In experimental study (Pastor, 2009), lifetime extension of the reinforced specimens is significant for patched comparatively to unpatched specimen. In recent experimental investigation of FCG behavior in heat-treated Al-alloys, performed on 2017 T4 and 6082 T6 (Borrego, 2010), a stress ratio and material dependence effects on the FCG were observed. FCG of patched and unpatched 6061 T6 Al-alloy plate was studied by Chung et Yang (2003). It was found that the fatigue life of patched plate increases about 4–6 times compared to the un-patched plate.

The aim in this paper is to investigate effect of bonded composite patch repair (Boron/Epoxy) on FCG of 6061 Al-alloy in two different state tempers (T6, T651). Under cyclic constant amplitude loading, stress ratio effect on patched structure was studied.

MATERIALS, SPECIMEN & FATIGUE CRACK MODELLING

Materials used in this study are 6061 in two temper states T6 and T651 in L-T orientation. Basic mechanical properties for these materials are presented in Table 1 (AFGROW database). Mechanical properties of composite patch (Boron/Epoxy) are indicated in Table 2. Simulation of fatigue crack growth in mode I used SENT specimen subjected to uniform tensile cyclic load. Geometrical parameters of tested specimens are indicated in Fig. 1.

Table 1 Mechanical properties of 6061 Al-alloys

Al-alloys	**$\sigma_{0.2}$ (MPa)**	**E (GPa)**	**K_{IC} (MPa.m$^{1/2}$)**	**K_C (MPa.m$^{1/2}$)**
6061 T6	292.7	68.95	28.75	49.99
6061 T651	303.4	68.95	29.67	59.34

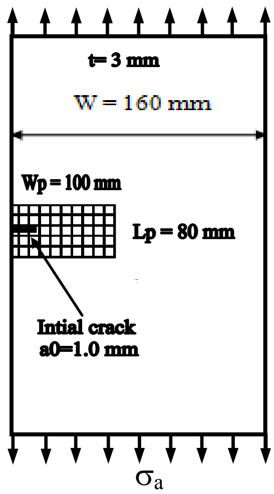

Fig. 1 Patched SENT specimen

Table 2. Mechanical properties of Boron/Epoxy

E_L (GPa)	**E_T (GPa)**	**G_{XY} (GPa)**	**ν**
206.84	19.31	5.17	0.2

The stress intensity factor for the studied specimen implemented in AFGROW code depends on several parameters is written bellow:

$$\Delta K = \sigma\sqrt{\pi a}.\beta(a/w) \quad (1)$$

Function β is the geometry correction factor, proposed by Newman (1976), is expressed below:

$$\beta(a/w) = \frac{0.752 + 2.02(a/w) + 0.37(1 - \sin\lambda)^3}{\cos\lambda\left[(2w/\pi a)\tan\lambda\right]^{0.5}} \tag{2}$$

where: $\lambda = \frac{\pi a}{2w}$ and $\frac{a}{w} \leq 1$

In patched specimen, function β depends on presence of composite patch and width of the patch and numbers of plies (Wp = 100 mm, 10 plies). Function β is given by Figure 2.

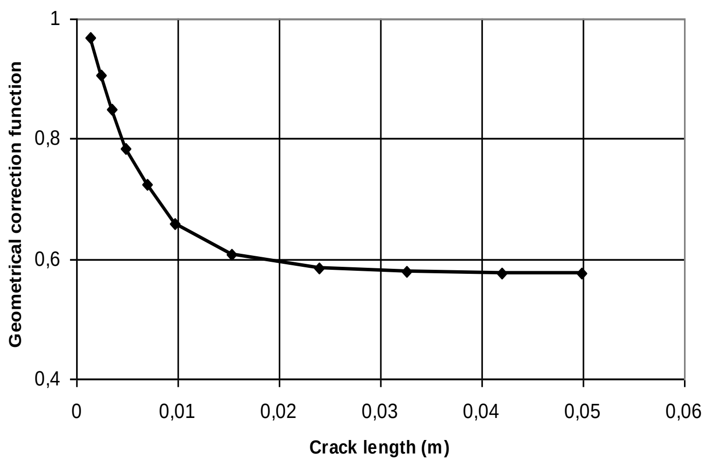

Fig. 2 Geometrical function correction β for patched SENT specimen

AFGROW code developed by NASA (Hareter, 2006) is used for simulation of fatigue crack growth. NASGRO model used in this study is expressed bellow and parameters of this model for the studied materials are presented in Table 3:

$$\frac{da}{dN} = C\left[\left(\frac{1-f}{1-R}\right)\Delta K\right]^n \frac{\left(1 - \frac{\Delta K_{th}}{\Delta K}\right)^p}{\left(1 - \frac{K_{max}}{K_{crit}}\right)^q} \tag{3}$$

Table 3 Parameters of crack growth model

Al-alloy	C	n	p	q
6061 T6	1.84×10^{-9}	2.30	0.5	0.5
6061 T651	2.73×10^{-9}	2.248	0.5	1

RESULTS

Patched and unaptched SENT specimen in T-L orientation are subjected to a constant cyclic loading (100 MPa) under variation of stress ratio. The K_{max} criterion was adopted for the limit of crack growth. This section provides and discusses the results from empirical analyses including the effects of various parameters/factors on fatigue life and FCGR of the repaired plate.

Fig. 3 shows the effect of stress ratio on fatigue life for un-patched and patched specimen in 6061 T61 Al- alloy. Same effects of R-ratio (0.1, 0.4) was shown for un-patched and patched specimen in 6061 T6 Al-alloy. It is noticed that an increasing in stress ratio increase the fatigue life. It is found that fatigue life of repaired specimen using 10 plies of composite patch is affected highly at high stress ratio (i.e R=0.4) comparatively to the low stress ratio. In patched specimen, for the same stress ratio, the fatigue life is about twice comparatively to the un-patched specimen. It is noticed that for patched specimen, limit resistance of fatigue crack growth is required at 64 mm of crack length but for un-patched is about 40 mm. The difference is this crack length presents a beneficial in service life.

Comparison between patched and un-patched plate in 6061 T651 Al-alloy is shown on Fig. 4. The same effect of stress ratio was shown for this material. Effect of heat treatment state T6 and T651 in 6061 Al-alloy on fatigue life is shown on Fig. 5 and Fig. 6 at stress ratio R=0.1 respectively for un-patched and patched plate by Boron/Epoxy. The fatigue life in T6 temper increases of about 114% comparatively to the T651 state.

In term of fatigue crack growth rate (FCGR), effect of heat treatment and composite patch repair are shown on Fig. 7. No effect of heat treatment state on FCGR. Of same, Fig. 7 shows the comparison of predicted FCGR between patched specimen repaired by Boron/Epoxy and un-patched specimen for both materials. It is clearly that patch repair retard crack growth rate. It is noticed a decreasing in FCGR after 4 mm of crack length for repaired specimen and FCGR for repaired specimens comparatively to un-repaired specimen in final crack is about 3 times.

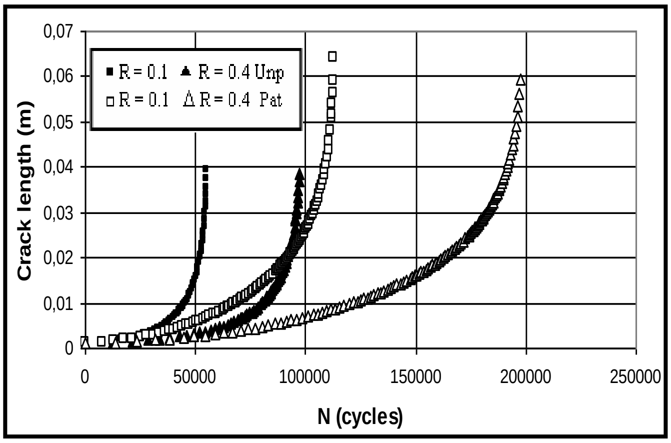

Fig. 3 Effect of composite patch repair on fatigue life for 6061 T6 Al-alloy

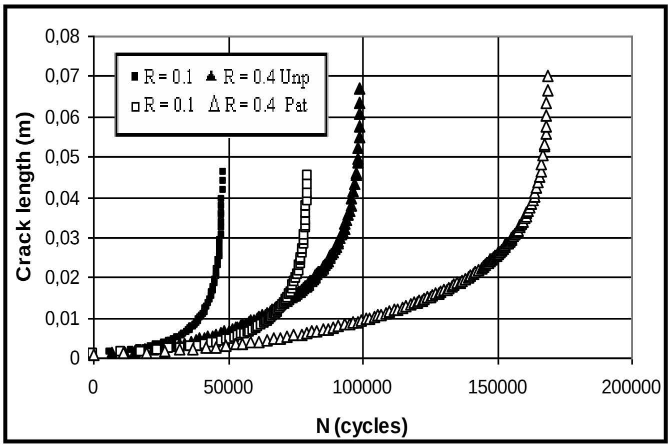

Fig. 4 Effect of composite patch repair on fatigue life for 6061 T651 Al-alloy

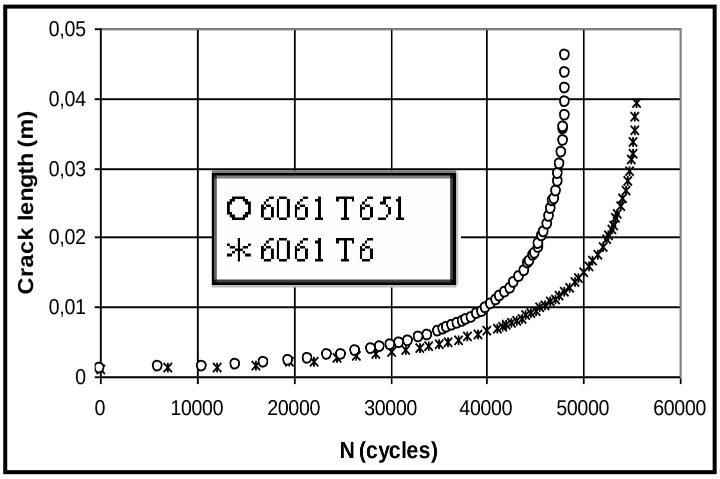

Fig. 5 Effect of heat treatment state on fatigue life for un-repaired specimen

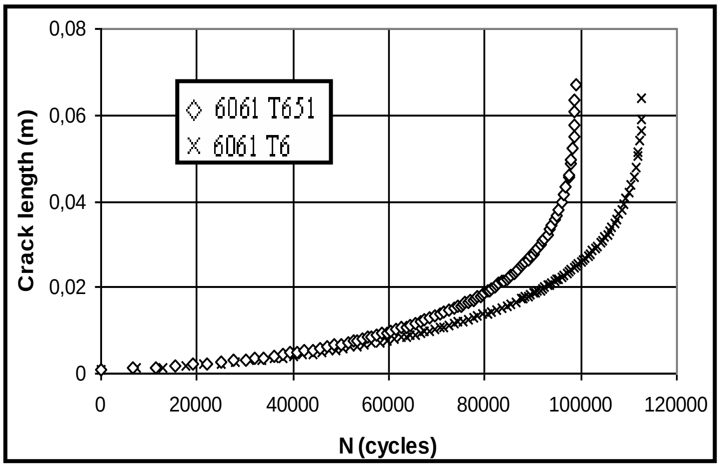

Fig. 6 Effect of heat treatment state on fatigue life for repaired specimen

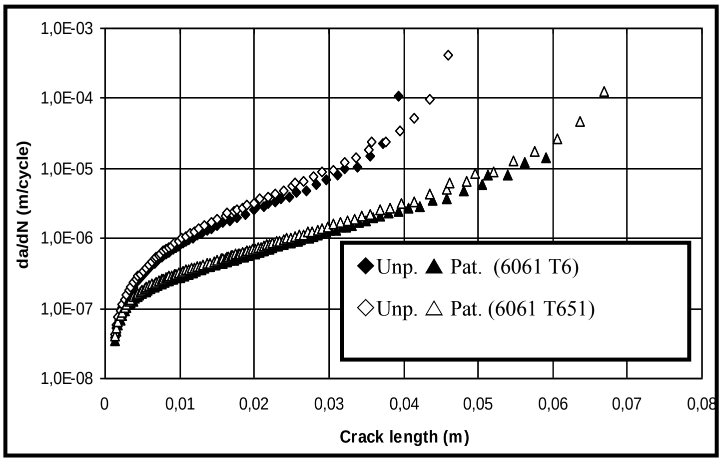

Fig. 7 Effect of composite patch and heat treatment state on FCGRs

CONCLUSION

This study involve fatigue behavior of 3 mm thin unrepaired and repaired “SENT” specimens by Boron/Epoxy in two tempered state of 6061 aluminum alloy (T6, T651). Conclusions of this study can be drawn:

* Fatigue life was affected by stress ratio for repaired and un-repaired specimen and no high difference in fatigue life was shown for specified heat state and is negligible in FCGR.
* Comparative fatigue behavior of repaired and un-repaired shows beneficial effect of composite patch repair and extension in service life.

ACKNOWLEDGMENTS

The authors gratefully acknowledge the funding by all research of team by IS2M Laboratory of Tlemcen.

REFERENCES

Borrego L.P, Costa J.M, Antunes F.V, Ferreira J.M. Fatigue crack growth in heat-treated aluminium alloys”. Engineering Failure Analysis, 2010, 17(1), p. 11–18.

Christian T.F. Jr., Hammond D.O., Cochran J.B. Composite material repairs to metallic airframe components. Journal Aircraft, 1992, 29, p. 470–476.

Chung C.S, Kim J.K, Kim H.K, Kim W.J. Improvement of high-cycle fatigue life in a 6061 Al alloy produced by equal channel angular pressing. Materials Science and Engineering, 2002, 337(1-2), p. 39-44.

Chung K, Yang W. A study on the fatigue crack growth behavior of thick aluminum panels repaired with a composite patch. Composite Structures, 2003, 60(1), p. 1–7.

Pastor M.L, Balandraud X, Robert J.L, Grédiac M. Lifetime prediction of aluminium structures reinforced with composite patches. Int. J. of Fatigue, 2009, 31, p. 850-858.