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EFFECT OF PATCH REPAIR ON FATIGUE BEHAVIOR

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Abstract: *In this paper, effect of patch repair on fatigue crack growth was investigated. In additional loading parameters associated with patch repair was studied in order to shown theirs influence on fatigue life and fatigue crack growth rate.*

Keywords: ***Composite patch repair, aluminum alloy, fatigue crack, stress ratio.***

1. Introduction

During navigation, aircrafts are subject to cyclic loading when damage was created in theses structures. In these situation fatigue problems become an important topic in the maintenance of damaged aircraft structures. Efficient repair technique, called composite patch repair, was used to reinforce the damaged (cracked) structures and extend the service life of aging aircraft. This technique offers significant advantages over traditional repair methods (riveting, fastening, welding). Repair of cracked components by an adhesively bonded composite patch has gained acceptance in aerospace structures (Baker et al., 2002). Beneficial effects of bonded repair can be summarized as: (1) reduction of the stress field near the crack, (2) leads to retardation or complete arrest of the crack growth, (3) provides a high structural efficiency and extends the life of cracked structural components at an economical cost. Investigation into the crack growth behavior of the bonded patch repaired structures has been the primary focus of the majority of previous studies (Sabelkin et al., 2006).

In experimental fatigue investigation conducted by Sabelkin et al. (2006) performed on 2024 T3 aluminum alloy and patched Boron/epoxy composite patch material, fatigue results shown that bonded composite patch repair increase fatigue life about fivefold in the case of stiffened panels while it increased about ten fold in the case of un-stiffened panels. In other work of Sabelkin et al. (2007), experimental and analytical investigation was conducted on 7075 T6 aluminum alloy panel repaired with one sided adhesively bonded composite patch. In this study, crack growth rate was primarily dominated by stress intensity factor of the repaired panel near the bonded patch and the bonded patch repair of a cracked panel provides a considerable increase in the residual strength as well as fatigue life. In review paper established by Jones et al. (2004) revealed that for composite repairs to through cracks in thin sheets the growth of small to medium length cracks, that have low to mid range ΔK's, follows the law proposed by Frost & Dugdale (1958) and Frost et al. (1974). Whenever to the precedent conclusion is valid and bending effects are negligible then the effect of the patch is primarily due to the reduction of the net section stress. In the investigation of Hosseini-Toudeshky (2006), it is experimentally and numerically shown that the crack growths non-uniformly from its initial position along the thickness of a single-side repaired panel and the crack-front shape are an important parameter influencing the stress intensity factor and crack propagation rate. In study conducted by Ong & Shen (1992), various factors affecting the repair of 2.5 mm thick 2024-T3

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aluminium plates have been investigated, especially patch materials. Effect of patch materials on FCG was studied namely boron/epoxy patch and graphite/epoxy patch. Modified walker equation was used to calculate fatigue crack growth. Results show that both boron/epoxy and graphite/epoxy composite patches attain sufficiently high fatigue lives to meet the damage tolerance requirement.

Fatigue behavior of patched aluminum alloys 2024 T3 and 7075 T6 was investigated by Duquesnay et al. (2005). Under constant amplitude loading, effect of stress ratio, R (R=-1, 0, 0.5), on stress life behavior was highlight. At same cycles of failure ($\approx 10^5$ cycles), an increasing in maximum shear stress was shown in increasing of stress ratio for the both aluminum alloys. In the same study, it was shown that patched bare 2024 T3 aluminum alloy present a good resistance comparatively to the unpatched bare. In recent work (Pastor et al., 2009), lifetime extension of the reinforced specimens is significant assuming the same load level for patched and unpatched specimens.

2. Fatigue crack growth behavior

2.1. Material and stress intensity factor for unpatched and patched specimen

Materials used in this study are 2024 T351 and 7050-T74 aluminum alloys obtained on rolled plates in L-T orientation. Basic mechanical properties for this material are presented in Table 1 (see Afgrow database). Mechanical properties of composite patch (Graphite/Epoxy) are indicated in Table 2. Simulation of fatigue crack growth in mode I used thin middle tensile plate specimen M(T) subjected to uniform tensile cyclic load. Geometrical parameters of tested specimens are indicated in Fig. 1.

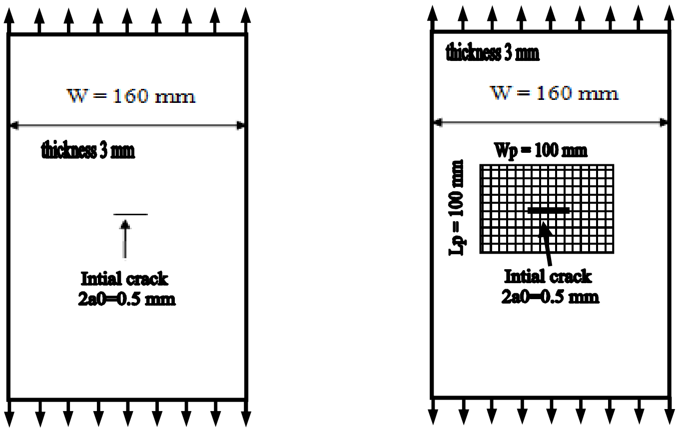

Fig. 1: M(T) specimen detail a) Unpatched specimen b) Patched specimen

Table 1. Mechanical properties of 2024 T351 Al-Alloy

E (GPa)	$\sigma_{0.2}$ (MPa)	K_{IC} ($MPa.m^{1/2}$)	K_C ($MPa.m^{1/2}$)	ν
73.08	372.32	37.36	74.72	0.3

Table 2. Mechanical properties of Graphite Epoxy

E_L (GPa)	E_T (GPa)	G_{XY} (GPa)	ν
172.37	10.342	4.826	0.3

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

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

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

$$\beta = \left[1 - 0.025\ \lambda^2 + 0.06\ \lambda^4\right]\left[\sec\left(\pi a/w\right)\right]^{0.5} \tag{2}$$

where λ=2a/w and a/w ≤ 0.5

In patched specimen function β was modified and depend on presence of composite patch and width of the patch and numbers of plies (Wp = 100 mm, 8 plies). Variation of recalculated function β is given on Fig. 2.

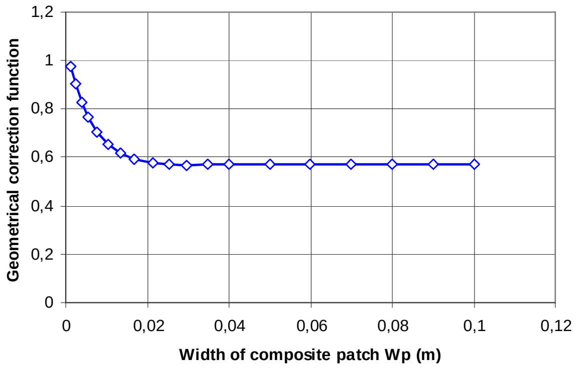

Fig. 2: Geometrical correction function β for patched M(T)specimen

2.2 Fatigue crack growth model

AFGROW code developed by NASA (Harter, 2006) is used for simulation of fatigue crack growth. In NASGRO model used in this study, is expressed bellow:

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

f presents 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. In constant amplitude loading, function f was determined by Newman (1984). Parameters of NASGRO model for the studied materials are presented in Table 3.

Table 3. Parameters of crack growth model for 2024 T351

σ_{max}/σ_0	C	n	p	q
0.3	1,7073e^{-10}	3.353	0. 5	1

3. Results & discussions

Patched and unaptched M(T) specimen in L-T orientation are subjected to a constant cyclic loading (σ_a=100 MPa) under variation of stress ratio. The K_{max} criterion was adopted for the limit of crack growth. Fig. 3 and Fig.4 showed respectively the effect of stress ratio on fatigue life for unpatched and patched specimen. For two configuration specimens, stress ratio presents the same effects. It is noticed that an increasing in stress ratio increase the fatigue life. It is found that fatigue life of repaired specimen using eight (08) plies of composite patch is affected highly at high stress ratio (i.e R = 0.5) comparatively to the low stress ratio. In all stress ratios, Fatigue life ratio patched/unpatched M(T) specimen is about twice (2) for crack length greater than 10 mm. In experimental fatigue life results (Seo & Lee, 2002) performed on CCT specimen at R =0.1, fatigue life ratio is about 3.5.

The fatigue crack growth rates for different stress ratio in unpatched specimens are shown on Fig. 5. Curves illustrate a general increase in da/dN with R. An important effect of R has been observed clearly for this material at high ΔK stress intensity factor. Also the same effect was shown in patched specimen. It is noticed that at same stress ratio, FCGRs for patched and unpatched specimen have the same slope and threshold stress intensity factor was influenced by patch repair (Fig. 6). Result shown that patched M(T) specimen crack at 5.6 MPa(m)$^{1/2}$ but for unpatched case, M(T) specimen crack at 2.8 MPa(m)$^{1/2}$ at zero stress ratio. For positive stress ratio, cracks grow at the same stress intensity.

Fig. 7 shows the comparison of predicted fatigue crack growth between patched specimen repaired by Graphite/Epoxy and unpatched specimen. It was showing clearly that patch repair retard crack growth. Aslo, it was noticed that after 10 mm of crack length, the difference in crack growth for the botch configuration specimen (Fig. 1) remains almost constant and between initial and 10 mm crack length, da/dN present a nonlinear variation.

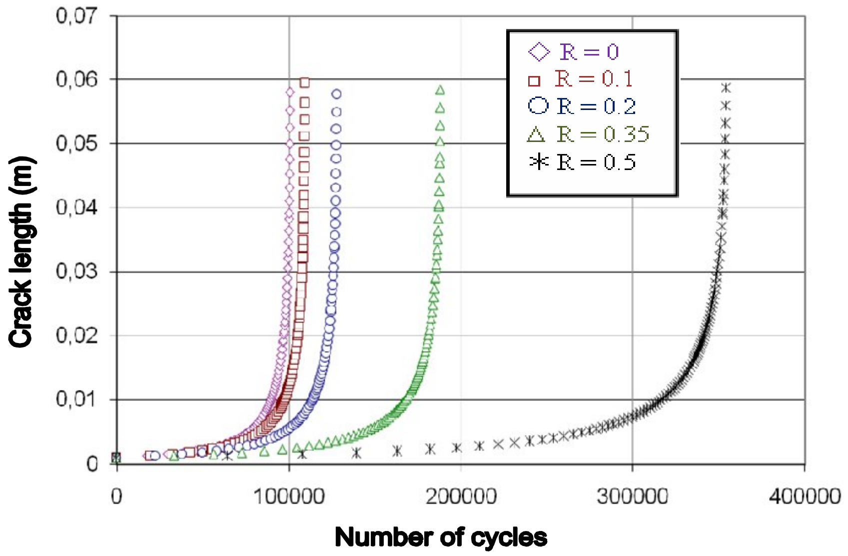

Fig. 3: Effect of stress ratio on fatigue life for unpatched M(T) specimen

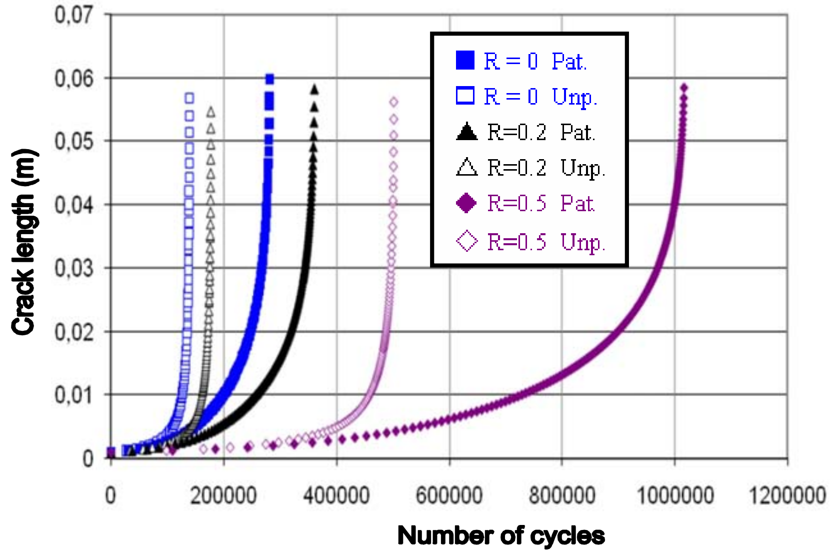

Fig. 4: Comparison and effect of stress ratio "R" on fatigue life for patched "Pat."and unpatched "Unp" M(T) specimen

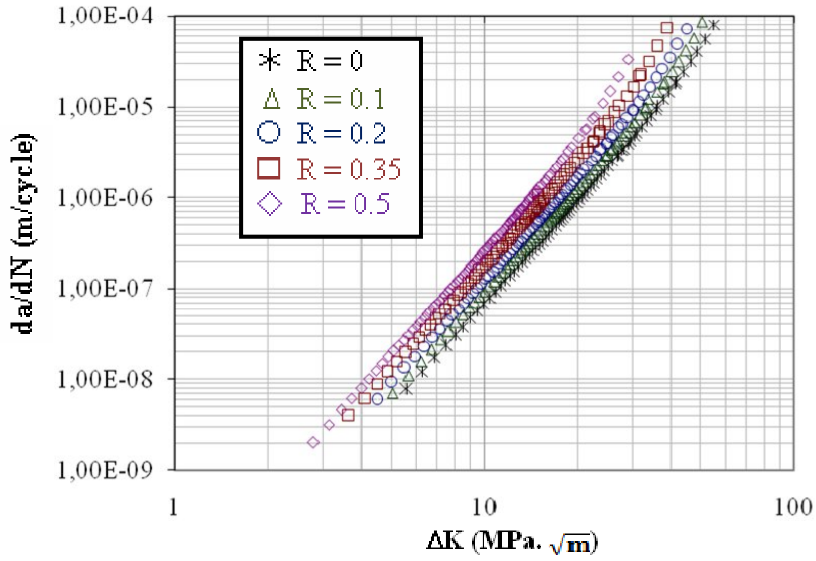

Fig. 5: Effect of stress ratio on FCGRs for unpatched M(T) specimen

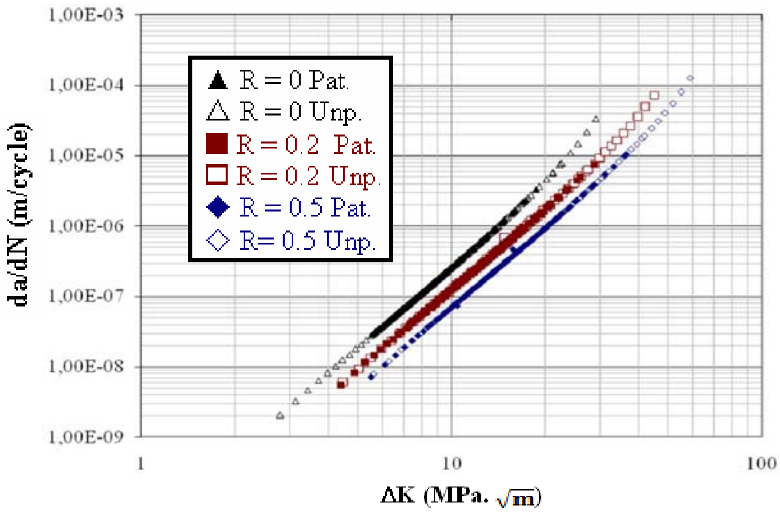

Fig. 6: Effect of stress ratio "R" on FCGRs for patched "Pat." And unpatched "Unp"M(T) specimen

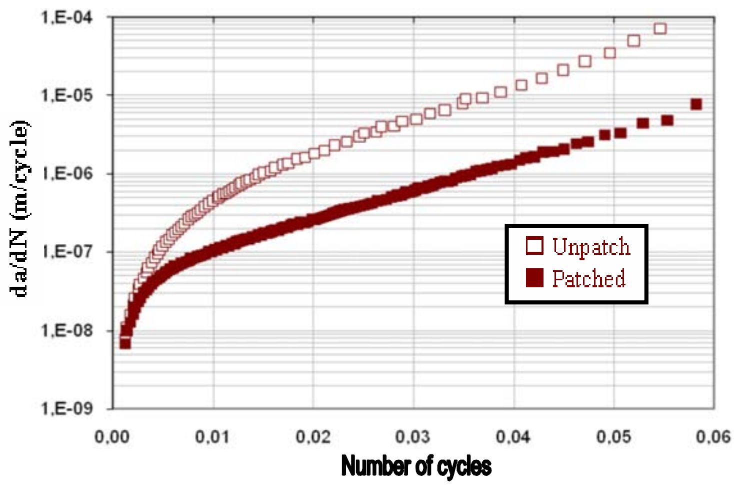

Fig. 7: Effect of patched and unpatched specimen on FCGRs performed on 2024 T351 Al-alloy M(T) specimen

4. Conclusions

Fatigue crack growth behavior of cracked plate with bonded composite patch repair was investigated through empirical study with numerical integration. This study involved fatigue behavior of 3 mm thin specimens with center crack M(T) unrepaired and repaired with four directional graphite/epoxy patch. Conclusions drawn from this study are cited below:

- Fatigue life for repaired and unrepaired specimen was affected by stress ratio.
- In repaired specimen fatigue life was affected highly at high stress.
- Fatigue crack growth rate (FCGR) increased by increasing in stress ratio.
- At the same stress ratio, patch repair affect threshold stress intensity factor and initial crack growth.
- Fatigue crack growth rate was compared for repaired and unrepaired specimen and shown beneficial effects of composite patch to extend the service life of damaged structures.

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