Engineering Fracture Mechanics 134 (2015) 182–201

Contents lists available at ScienceDirect

Engineering Fracture Mechanics

journal homepage: www.elsevier.com/locate/engfracmech

Fatigue crack growth study of CFRP patch repaired Al 2014-T6 panel having an inclined center crack using FEA and DIC

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ARTICLE INFO

Article history:
Received 31 July 2014
Received in revised form 11 December 2014
Accepted 18 December 2014
Available online 27 December 2014

Keywords:
Aluminium alloys
Cohesive zone modeling
Digital image correlation
Fatigue crack growth
Bonded joints

ABSTRACT

In this work, the fatigue life of unrepaired and repaired Al-2014-T6 panels with an inclined center crack is investigated. Cracked panels are repaired through single- and double-sided adhesively bonded carbon fiber reinforced polymer (CFRP) patch. The fatigue crack growth is monitored experimentally using digital image correlation and numerically using 3D finite element analysis. The adhesive-interface between the panel and patch is modeled using bilinear cohesive law. The CFRP/Al-2014-T6 adhesive-interface properties are obtained from the baseline tests. Fatigue life of double-sided repaired panel is observed to be twice that of single-sided. And non-uniform crack front is observed in single-sided repaired panels.

1. Introduction

Aging aircrafts accumulate fatigue cracks during their operation and often needs repairs to increase their service life. One can repair the cracked aircraft structures by using adhesively bonded composite patches. The role of a bonded composite patch is to restore the strength by reducing the stress intensity factor (SIF) near the crack tip [1]. It offers many advantages over the mechanical fastenings or riveting. These include, reduced stress concentration, efficient load transfer, improved fatigue behavior, restored stiffness and strength, reduced corrosion and handling of complex patch configuration. Repair of the aircraft aluminum structures using the composites patches has been initiated by Baker et al. [2] in the early 1970s to enhance the fatigue life of cracked aircrafts structures. Mostly, patch material is Carbon/Boron Fiber Reinforced Plastic (FRP) laminate. Typically, there are two types of patch work that are prevalent in composite repair: single-sided (un-symmetrical patch) and double-sided (symmetrical patch) repair. Mostly, the double-sided patch work is preferable over the single-sided repair as they are capable of higher SIF reduction [3]. However, due to operational feasibility single-sided repairs are mostly preferred.

Several researchers in the past have used FEA to model the composite patch repaired panels [1–12]. Seo and Lee [4] have carried out both numerical and experimental studies on the fatigue crack growth (FCG) behavior of the thick cracked panel repaired with a single-sided composite FRP patch. They have studied panels with both skewed and uniform crack front for the fatigue life estimation involving FEA. They found that, in the single-sided repairs, skewed crack front modeling predicted the fatigue life more accurately as compared with the experiments. Lee and Lee [5] performed the experimental and

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http://dx.doi.org/10.1016/j.engfracmech.2014.12.012
0013-7944/

Nomenclature

$2a$	crack length
C, m	fatigue material constants
da	crack growth increment
da/dN	crack growth rate
E	Young's modulus
E_a	Young's modulus of adhesive
E_{xx}	modulus in x direction
E_{yy}	modulus in y direction
E_{zz}	modulus in z direction
F_{xi}, F_{yi}, F_{zi}	reaction force at crack tip node i along x, y and z-direction
G_{Ic}	critical interface fracture toughness in mode I
G_{IIc}	critical interface fracture toughness in mode II
G_{eq}	equivalent energy release rate
G_{ERR}	energy release rate
G_{xy}	in plane shear modulus x–y plane
G_{xz}	out of plane shear modulus x–z plane
G_{yz}	out of plane shear modulus y–z plane
k_I	stiffness of the adhesive
k_I'	stiffness after degradation
K_I	mode I stress intensity factor
K_{II}	mode II stress intensity factor
K_{III}	mode III stress intensity factor
K_{eq}	equivalent stress intensity factor
ΔK_c	critical value of SIF range
ΔK_{th}	threshold SIF value
P_{max}	maximum load
R	load ratio
t_a	adhesive thickness
u_j, v_j, w_j	displacements at node j along x, y and z direction respectively
u_m, v_m, w_m	displacements at node m along x, y and z direction respectively
V_i	relative displacement along y-direction
V_{ii}	relative displacement along x-direction
V_{iii}	relative displacement along z-direction
β	crack inclination angle
δ_{max}	maximum displacement in mm
θ	crack propagation angle
μ	shear modulus
ν	Poisson's ratio

Abbreviations

FRP	fiber reinforced polymer
CFRP	carbon fiber reinforced polymer
CZM	cohesive zone modeling
ERR	energy release rate
FEA	finite element analysis
FCG	fatigue crack growth
SIF	stress intensity factor
VCCT	virtual crack closure technique

numerical studies on the FCG behavior of the aluminum plate with a straight crack repaired with single-sided composite patch. They observed that the single-sided repair is effective for the thin plates as compared to thicker ones. Tsai and Shen [6] have performed both the experimental and numerical analysis of thick aluminum panels repaired using the single-sided Boron FRP patch and investigated the fatigue crack propagation characteristics. Tay et al. [7] have carried out the experimental investigation of an aluminum panel with a cracked bolt hole repaired with the Boron FRP patch. They showed that the patched specimens with the press-fitting plugs survived longer than the notched specimens with a very little crack growth. Schubbe and Mall [8] have conducted the experimental analysis on the FCG behavior of both thick and thin aluminum panels repaired with a single-sided patch. They have done a parametric study varying the stiffness ratio as well as patch length and