Composites: Part B 44 (2013) 266–273

Contents lists available at SciVerse ScienceDirect

Composites: Part B

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

Accelerated ageing behaviors of aluminum plate with composite patches under salt fog effect

S.W. Wen [a,*], J.Y. Xiao [a], Y.R. Wang [b]

[a] College of Aerospace and Materials Engineering, National University of Defense Technology, Changsha, Hunan 410073, PR China
[b] Army Aviation Institute of PLA, Beijing 101123, PR China

ARTICLE INFO

Article history:
Received 29 December 2011
Received in revised form 8 May 2012
Accepted 22 May 2012
Available online 1 June 2012

Keywords:
A. Polymer–matrix composites (PMCs)
B. Environmental degradation
B. Fatigue
D. Mechanical testing

ABSTRACT

The present study investigated the salt fog effect on the quasi-static tensile and fatigue properties of the center-cracked aluminum plates which were single-sidedly repaired with C_f/epoxy composite patches. The results show that the salt fog has minimal impact on the quasi-static tensile properties of the epoxy resin and C_f/epoxy composites; while the quasi-static tensile and fatigue properties of the repaired and unrepaired specimens all decrease with the exposure time of the salt fog increasing. Compared to the unrepaired specimens, the repaired specimens have high resistance to salt fog degradation. Within the 0–900 h range of exposure time, the repaired specimens completely fail when the fatigue crack length is equal to the width of the aluminum plate. However, as the exposure time is larger than 900 h, the repaired specimens can still bear fatigue loading when the fatigue crack propagates through the aluminum plate.

1. Introduction

For the high effectiveness, the bonded composite patch method is taken to increase the endurance of the cracked aircraft structures and evaluate their safety [1–3]. One of the successful cases of bonded patch repair of thin metallic plates in aircraft structures is carried out in fuselage skins damaged by fatigue loading [4,5]. And a cracked marine metal structures repaired with composite patch had serviced for 15-year in Australia [6]. Planes and ships are often exposed to various environmental conditions at different altitudes, such as force + temperature + humidity, salt fog, UV radiation from the sun, and so on. The environment can influence the properties of the composite metal interface, composites and the metal, and then degrades the properties of the repaired structures.

Megueni et al. [7] investigated the fracture mechanism of the cracked aluminum plate repaired with composite patches that were aged with hygrothermal effect and under the effect of unidirectional tensile stress. Researchers observed that humidity and temperature (hygrothermal) had a negative effect on the fracture. Ergun et al. [8] investigated experimentally and numerically the fatigue life of the cracked 2024-T3 aluminum plates repaired with patches made of unidirectional composite plates for hygrothermal effect. The problem was handled in plane stress and Mode I condition. They found that at room temperature, as humidity increases from 45 ± 5% to 85 ± 5%, changes of K_I/K_C is about 1%, but at $T = 100$ °C, it is 4–5%.

Armstrong [9] studied the long-term durability in distilled water of aluminum plate adhesive joints bonded with epoxy adhesives. He found that the durability of adhesive bonds depends on the permeability of the adhesive towards water. Scott [10] reviewed the study of the environmentally induced or assisted cracking of the offshore metal structure in the UK. Several key generic issues were highlighted, such as the relevance of short term test methods to long term service experience and the increasing reliance on fracture mechanic analyses with their strengths and weaknesses for facilitating run/repair decisions. Benzarti et al. [11] investigated the durability of the adhesive bond between concrete and carbon fiber reinforced polymers strengthening systems under accelerated ageing conditions. They suspected that the moisture diffusion from the superficial layer of concrete towards the adhesive joint is a key factor driving the degradation process during hydrothermal ageing.

Seawater attack on metal structures can be a serious problem in humid and marine environments. Water absorption can be detrimental to fatigue strength of composites [12]. The reduction of fatigue strength was caused by the degradation of both fiber and matrix. A hygrothermal effect was found to reduce fatigue limit; however, aging duration by seawater is more effective than temperature. Some mechanical tests also demonstrated an increase in the rate of damage as a function of water content [13]. However, the initial fatigue properties may be recovered by removing the

* Corresponding author. Tel.: +86 731 8457 3182; fax: +86 731 8457 6578.
E-mail address: wensiwei@hotmail.com (S.W. Wen).

1359-8368/$ - see front matter © 2012 Elsevier Ltd. All rights reserved.
http://dx.doi.org/10.1016/j.compositesb.2012.05.024

absorbed water. Toutanji [14] conducted several research topics on concrete columns confined by composites subjected to environmental fatigue. The environmental fatigue included seawater, and the reinforced materials could be either composite jackets or composite sheets. They achieved important findings. First, selection of the matrix type is very important for using polymer composites in a marine environment. Second, carbon fibers perform is better than glass fibers under seawater attack. Liu et al. [15] studied the effect of seawater on compressive strength of concrete cylinders reinforced by non-adhesive wound hybrid polymer composites. They found that both material type and environmental condition could influence the strength reduction of composite/concrete system subjected to seawater absorption or air aging.

Even with all experiences and knowledge gained through the studies, there is a significant void in salt fog effect on the quasi-static tensile and fatigue properties of the cracked aluminum plates repaired with composites patches, which was the motivation of the present effort.

In this study, the quasi-static tensile properties of E-51 epoxy matrix and the unidirectional T300/E-51 carbon fiber reinforced epoxy composite (C_f/epoxy composites) after salt fog exposure were studied. Then the quasi-static tensile and fatigue properties of the center-cracked aluminum plates single-sidedly repaired and unrepaired with C_f/epoxy composite patches after salt fog exposure were investigated.

2. Experiment

2.1. Materials

The center-cracked plates (the unrepaired specimens) were made of LY12CZ aluminum plate with a thickness of 1.76 mm. The chemical compositions of LY12CZ plate are given in Table 1, and the properties are given in Table 2.

For the patch, the unidirectional T300/E-51 carbon fiber reinforced epoxy composite (C_f/epoxy composites) material was used. T300 carbon fiber is made by Torayca Industry Co. E-51 epoxy matrix made by Yueyang Epoxy Company is liquid bisphenol-A diglycidyl ether, its mean epoxy value is 0.51. Polyurethane (PU) modified epoxy made by Heilongjiang Institute of Petrochemistry was used as adhesive to bond the patch and the cracked aluminum plate. The properties of the composite patch and adhesive are given in Table 2.

2.2. Specimens

The aluminum plates were 280 mm long and 60 mm wide (Fig. 1), the grain in material was along with the length direction of the aluminum plates. The cracked aluminum plate (the unrepaired specimens) contained an initial center crack length (a) of 14 mm. For the unrepaired specimens, the initial crack with the crack length of 10 mm and the crack width 0.2 mm was cut by using wire-cut technique in the center of each specimen, followed by the production of fatigue crack by using a resonant fatigue-testing machine to reach a crack size of a = 14 mm. The bonded surface of the aluminum plate was treated by the Phosphoric acid anodizing (PAA) method [16].

Table 1
Chemical compositions of LY12CZ aluminum plate.

Trademark	Composition (wt%)								
	Cu	Mg	Mn	Fe	Si	Zn	Ni	Ti	Al
LY12CZ	4.36	1.57	0.54	0.43	0.25	0.2	<0.05	0.04	Left

The composite patch was bonded on one side of the aluminum plate as shown schematically in Fig. 1. The C_f/epoxy composite patches were 100 mm long and 60 mm wide. It has been found that the patch is most effective when the patch stiffness (E_pt_p) is equal to the aluminum plate stiffness (E_st_s) [17]. Where E_p and E_s are the modulus of elasticity of composite patch and aluminum plate, respectively; t_p and t_s are the thickness of the composite patch and aluminum plate. So the thickness of the patches in this study was 0.92 mm. All plies in the patch have unidirectional lay-up where the fibers were oriented along the specimen length direction (parallel to the direction of load). All patches were bonded with a 0.1 mm thick layer of Polyurethane (PU) modified epoxy.

The patches were pre-cured before bonding to the aluminum plates. Thus, the patches were vacuum bagged and cured at 72 °C for 3 h and 90 °C for 1 h. Cure cycle involved a single ramp of heating at a rate of 3–5 °C/min, cooling down at 10 °C/min (with the full pressure) to 35 °C and then the pressure was released and the heat turned off.

2.3. Salt fog test

The GB2423.17-81 Salt Fog test is an accelerated corrosion test by which specimens exposed to the same condition can be compared and thereby the effect of salt fog on the properties of the repaired and unrepaired specimens can be studied. In the salt fog test, the specimens were exposed to a salt fog generated from a 5 ± 1wt% sodium chloride solution. The temperature in the chamber was held at 35 ± 1.1 °C. All specimens were placed in the YWX/Q-250C salt fog chamber. Specimens were taken out from the salt fog chamber at 200 h intervals and subjected to quasi-tensile and fatigue properties testing.

2.4. Experiment conditions

2.4.1. Quasi-static tensile test

Quasi-static tensile test was carried out in both the repaired and unrepaired specimens by using a WDW-100 electromechanical testing machine. The specimens were loaded with a displacement speed of 2 mm/min. Elongation of the aluminum plate in specimen was recorded with two extensometers, as shown in Fig. 2.

The quasi-static tensile properties of the epoxy matrix and C_f/epoxy composites were carried out by using a WDW-100 electromechanical testing machine with the GB/T 2568-1995 and GB/T 3354-1999, respectively. And the micro-structural characterization of the C_f/epoxy composites was carried out by means of scanning electron microscopy (SEM).

2.4.2. Tensile-tensile sinusoidal fatigue test

All fatigue tests were operated at 90 Hz with a sinusoidal waveform, the stress ratio (R) of 0.1 and the maximum stress of 100 MPa by the PLG-100C resonant fatigue-testing machine. The un-patched side of the specimen was polished by the standard metal polishing method for crack measurement. For accurate crack length measurement, the image of crack length at intervals was got by digital camera, and then the crack length in the image was measured by the image software. All tests were conducted under ambient laboratory environment. At least three specimens for each salt fog exposure time were prepared and tested to evaluate the variation which was less than ±15%.

2.5. Evaluation of the salt fog effect on the properties of the specimens

In quasi-static tensile test, the so-called effect of the salt fog on the properties of the specimens was defined and characterized by the reservation of loading capacity (η), resumption of loading