DEVELOPMENT OF A SMART COMPOSITE PATCH METHODOLOGY FOR THE CONTINUOUS HEALTH MONITORING OF AIRCRAFT REPAIRS

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ABSTRACT

The present paper presents a methodology for the development of smart composite patches by embedding Bragg grating optical fiber sensors for the continuous health monitoring of a composite patch repair. It has been established that for composite patch repairs the most critical area is the interface between the aluminium substrate and the composite patch. A series of specimens simulating typical smart composite patch repairs on a cracked aircraft wing skin were manufactured and tested .A manufacturing process was developed by embedding Bragg grating sensors into the composite patch. Artificial debonds were created at the interface between the adhesive and the aluminium substrate and tension tests were carried out. Strains were measured by fiber Bragg grating sensors located between plies 6 and 7 in the boron patch above the crack tip. They were continuously monitored during the test. The specimen was mounted on a tension machine and the Bragg fiber interrogating system was connected to the embedded optical fiber. The specimen was sequentially loaded and unloaded up to 1, 3, 5, 7, 10 kN and strains were recorded. The test was performed under conditions of displacement control. The test results were correlated with reference curves obtained from healthy composite repairs under the same tension loading spectrum. A warning method was established for recording a pre-critical repair condition taking into consideration the critical substrate stress intensity factor and the relevant strain measurements during the debond evolution.

1. INTRODUCTION

Repairs based on adhesively bonded composite patches or reinforcements are attractive for many airframe repair applications because, compared to traditional repair techniques based on mechanically fastened metallic patches, they offer cheaper, quicker and more durable repairs [1-7]. Other advantages include more uniform and efficient load transfer into the patch, reduced stress concentrations, thinner patches, easier application to double curvature surfaces and reduced risk of corrosion. Furthermore, for some applications bonded composite patching may be the only alternative to costly component replacement.

Fiber optic sensor technology has grown rapidly to the level where it is being used in a wide variety of material and structural monitoring applications. Fiber optic sensors have the advantages of geometric versatility of the sensing element, sensor multiplexing capabilities, wide dynamic range and high sensitivity. In the present work optical fiber Bragg sensors are used to monitor the health of a composite patch repair. A Bragg sensor uses a Bragg grating which is a periodic variation of the index of refraction of the core of the optical fiber along the length of the fiber. The variation of the index of refraction is formed by exposure the fiber core to an intense optical interference pattern of ultraviolet light.

In the present work a series of specimens simulating typical smart composite patch repairs on a cracked aircraft wing skin were manufactured and tested .A manufacturing process was developed by embedding Bragg grating sensors into the composite patch. Artificial debonds were created at the interface between the adhesive and the aluminium substrate and tension tests were carried out. Strains were measured by fiber Bragg grating sensors located between plies 6 and 7 in the boron patch above the crack tip. The test results were correlated with reference curves obtained from healthy composite repairs under the same tension loading spectrum. A warning method was established for recording a pre-critical repair condition taking into consideration the critical substrate stress intensity factor and the relevant strain measurements during the debond evolution.

2. MATERIALS AND SPECIMENS

Two types of specimens, type I and type II, were prepared (Fig. 1). The type I specimens were tension coupons with an embedded optical fiber (Fig. 2). They were made of Textron 5521 boron / epoxy prepreg cured in the autoclave. Glass / epoxy tabs were cocured with the boron / epoxy prepreg for gripping the specimens in the loading machine.

The type II specimens are cracked coupons patched with composite patches. The cracked coupon was made of Al 2024-T3 aluminum alloy and the patch of Textron 5521 boron / epoxy prepreg (Fig. 3). The boron prepreg is adhesively bonded onto the aluminum plate via Araldite 5138 epoxy adhesive. The process used for curing was hot bonding.

An optical fiber was introduced in both specimen types. A metallic protector has been used at the ingress point in order to prevent the optic fiber from breaking. In both cases, the optical fibers were (temporarily) positioned onto the prepreg with tape.

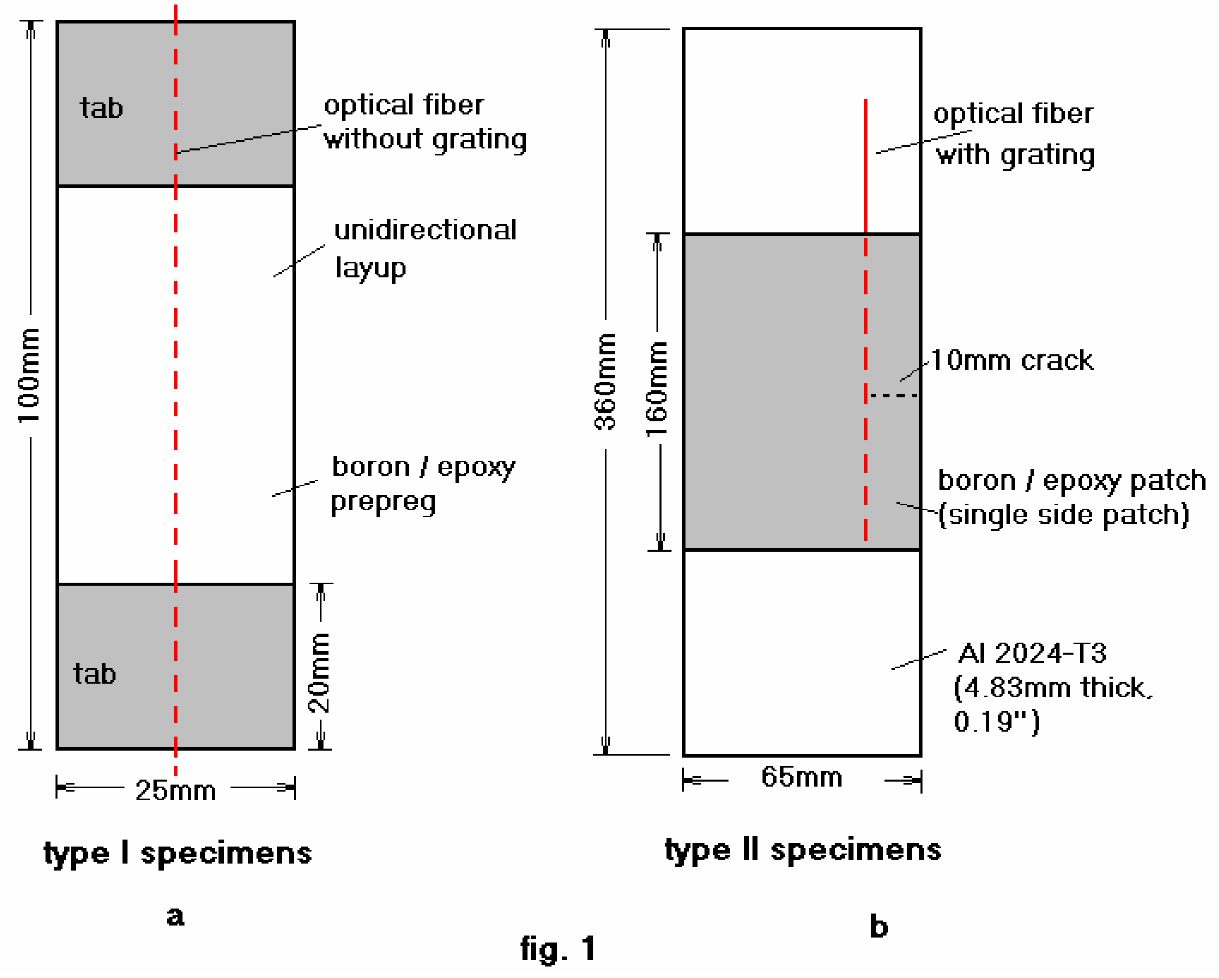

Fig. 1. Type I and type II specimens

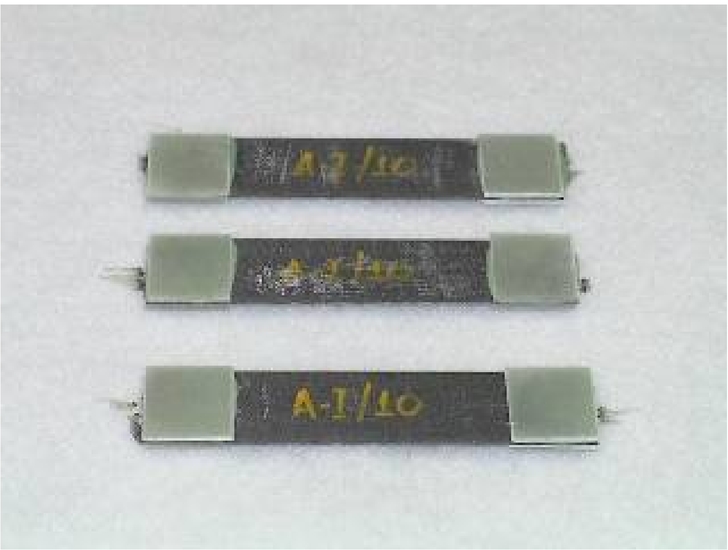

Fig. 2 . Type I specimens with Bragg optical fibers

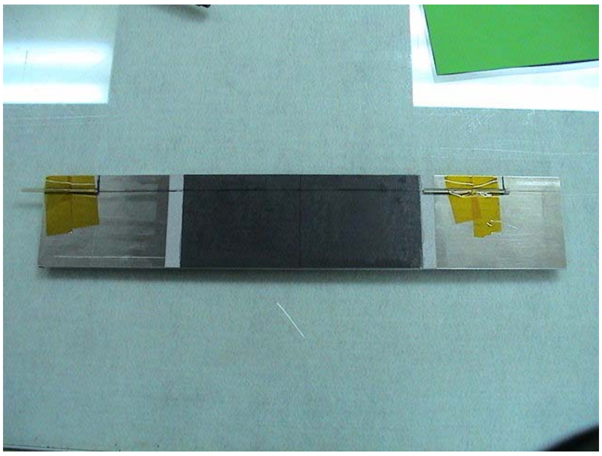

Fig. 3. Type II specimens with Bragg optical fibers

3 EXPERIMENTAL

A series of tensile tests on type I specimens has taken place in order to calibrate the optical fiber. The specimens were loaded up to fracture.

The series of reliability measurements tests have been performed and a test has been executed on a type II specimen with a 7-ply patch. The experiment concerned the monitoring of strains via a fiber Bragg grating sensor located between plies 6 and 7 in the boron patch above the crack tip. The specimen was mounted on a tension machine and the fiber Bragg interrogating system was connected to the embedded optical fiber. The specimen was sequentially loaded and unloaded to 1, 3, 5, 7, 10 kN and strain measurements were recorded. The test was performed under displacement control.

4 RESULTS

Fig. 4 shows the strain measured by the fiber Bragg grating as a function of time, while Fig. 5 shows the applied load as a function of grip displacement (time). Finally, Fig. 7 shows the corresponding strain versus load curves.

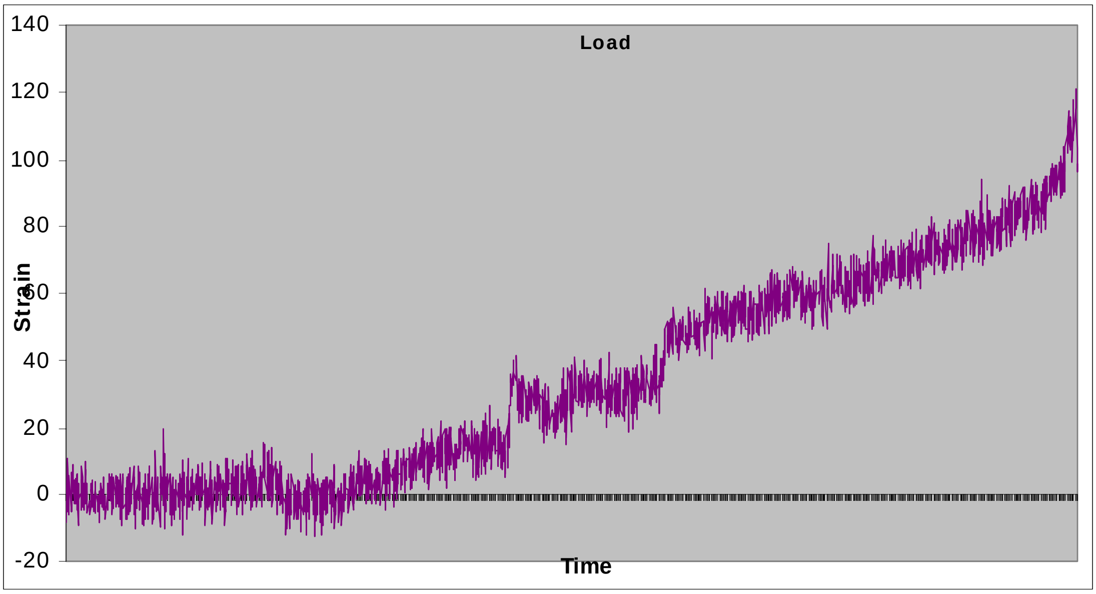

Fig. 4. Strain versus time curve obtained by the Bragg optical fiber measurements

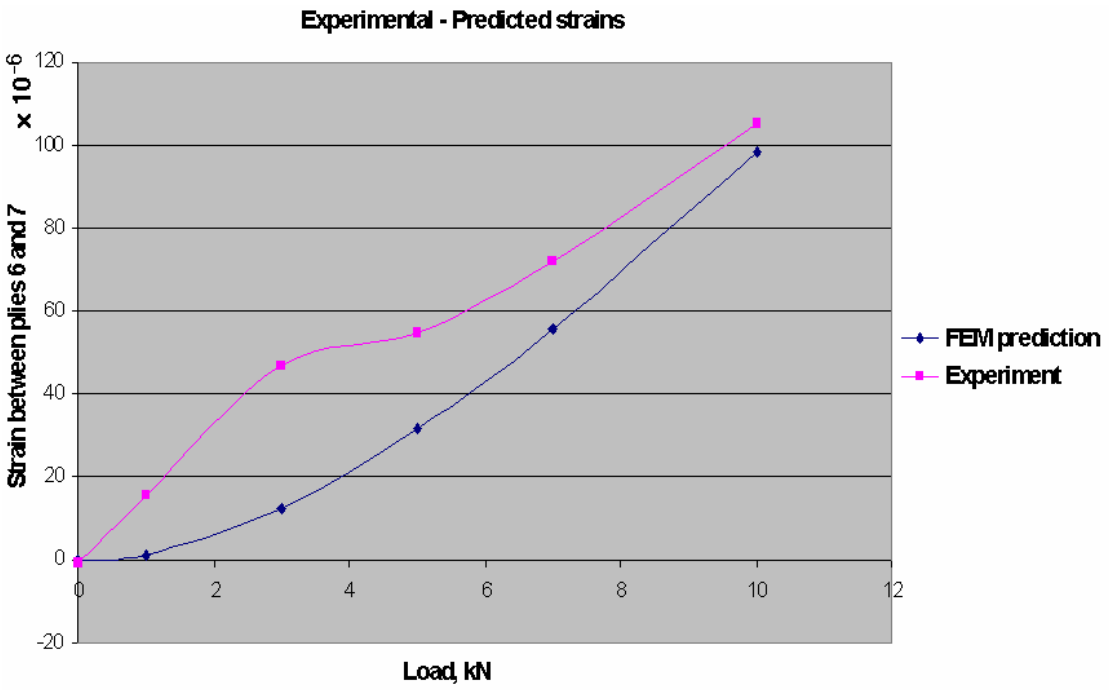

Fig. 5. Experimental and finite element curves of strain versus load. Strains are measured in the composite patch between plies 6 and 7.

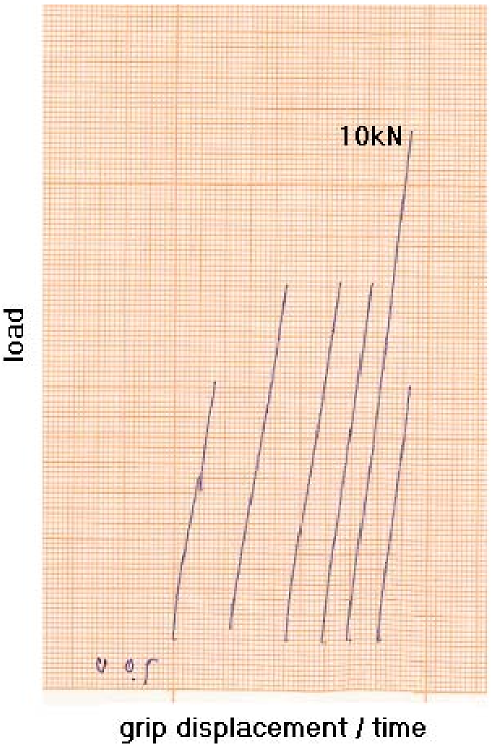

Fig. 6. Load versus grip displacement curves

References

1. **Marioli-Riga, Z., Tsamsphyros, G.,** and **Kanderakis**, G. “Development of a method for A/C emergency repairs by composite patches”, S.A Paipetis and E.E.Gdoutos, (Xanthi 1997), Vol II, 143-156.
2. “Composite repairs of cracked metallic airframe structures”, U.S. Department of Transportation, Federal Aviation Administration, CT-92/32 (May 1993).
3. **Fredell R.** and **Mazza J**., “Fatigue in new and ageing aircraft – The development of an integrated bonded repair system”, 19th International Committee on Aeronautical Fatigue Symposium, Edinburgh, Scotland, June 1997.
4. **Baker A.A** and **Jones R.,** “Bonded repair of aircraft structures”, Martinus Nijhoff Publishers, Dordrecht, (1988).
5. **Baker A.A.,** “Bonded composite repair of metallic aircraft components – Overview of Australian Activities”, AGARD, CP-550.
6. “An introduction to fatigue in metals and composites”, R.L.Carlsson and G.A. Kardomateas, 1996, Chapman & Hall, London.
7. Tsamasphyros, G.J., Kanterakis, G.N., Karalekas, D., Rapti, D., Gdoutos, E.E., Zacharopoulos, D. and Marioli-Riga, Z.P., "Study of composite patch repair by analytical and numerical methods", Int. J. Fat. Fract. Eng. Mat. Struct., **24**, (2001), 631-636.