Materials and Design 30 (2009) 590–595

Contents lists available at ScienceDirect

Materials and Design

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

Modelling of a cracked aluminium plate repaired with composite octagonal patch in mode I and mixed mode

D. Ouinas [a,*], B. Bachir Bouiadjra [b], B. Achour [a], N. Benderdouche [a]

[a] Faculty of Engineering, University Ibn Badis of Mostaganem, 27000, Algeria
[b] LMPM, Department of Mechanical Engineering, University of Sidi Bel Abbes, 22000, Algeria

ARTICLE INFO

Article history:
Received 13 April 2007
Accepted 22 May 2008
Available online 17 July 2008

Keywords:
Octagonal composite patch
Cracks and adhesives
Stress intensity factor (SIF)
Finite element analysis

ABSTRACT

Adhesively bonded composite patch repair technique has been successfully applied in military aircraft repair and has recently been expanded to commercial aircraft industry. This technique is applied to extend the service life of cracked aluminium components. In this paper, the finite element method is applied to analyse the central crack's behaviour repaired by a boron/epoxy composite patch. The effects of the mechanical and geometrical properties of the patch on the variation of the stress intensity factor at the crack tip were highlighted. The obtained results show that the stress intensity factor at the crack tip, repaired by an octagonal patch of height $2c/3$, is reduced by 5% with regard to the one repaired by an octagonal patch of size 'c'. For a height patch of $c/3$ the reduction is about 7%. The maximum reduction of composite patch of fibres in y-direction is about 30% compared to the aluminium patch. This reduction doubles when a composite patch of fibres in x-direction is used. The adhesive properties must be optimised to increase the performance of the repair of structures by such reinforcement.

1. Introduction

Recently, the use of adhesives is accepted as a process of structure repair to increase the service life of damaged components. The metal or composite patches are stuck on a single or on both faces of the cracked structural components [1–6]. The repair of the cracks by gluing composite material patches proved its efficiency in reducing the stress intensity at the crack heads. This method has been successfully used in repairing damaged plane components.

Considerable work has been done to develop the technique of fitting the composite patches on aeronautical structures [7–9].

Among the several advantages offered by bonded patches, one can mention the following; the improvement of the fatigue life of the material, the reduction of corrosion and the easy fit to a complex aerodynamic contour. The determination of the SIF at a crack tip is one of the possible means for analysing the performances of the composite patches.

It is well-known that the finite element method gives with a high precision the SIFs at the crack tip. Among the authors having used this method in the case of reinforced cracks; one can quote [10–14]. The work carried out on the repair of a crack emanating from a semicircular notch by a composite patch [15], can also be mentioned.

The aim of this study is the analysis of the behaviour of a crack reinforced in an aluminium plate in mode I and mixed mode using the finite element method. The composite patch under analysis is the boron/epoxy which had been used successfully in aeronautical repair. Various authors [11,13] showed that in practice the parameters influencing the performance of the repair are the properties of both the patch and the adhesive. For this purpose, the effects of the adhesive shear modulus, its thickness as well as the thickness of the patch on the variations of the SIF of a composite patch having a fixed height 'c' are examined. The comparison of the results obtained by the use of an octagonal patch with different heights is highlighted.

2. Geometrical model

In this model, an aluminium thin rectangular plate having the following dimensions: length $H_P = 203.2$ mm, width $w_P = 152.4$ mm and the thickness $e_P = 1$ mm had been considered. A crack length $2a = 20$ mm located in the middle of the plate and perpendicular to the solicitation plane was supposed. The plate was then subjected to a uniaxial tensile stress $\sigma = 120$ MPa.

The crack is repaired using a bonded boron/epoxy patch which is considered as an orthotropic material having the following dimensions: $c = h = 60$ mm and the thickness $e_R = 1$ mm (Fig. 1). The properties of the patch material are: Young's modulus E_R and the Poisson's ratio ν_R. The adhesive properties are: the shear modulus G_a and the thickness $e_a = 0.127$ mm. Due to the symmetry of

* Corresponding author.
E-mail address: douinas@netcourrier.com (D. Ouinas).

0261-3069/$ - see front matter © 2008 Elsevier Ltd. All rights reserved.
doi:10.1016/j.matdes.2008.05.040

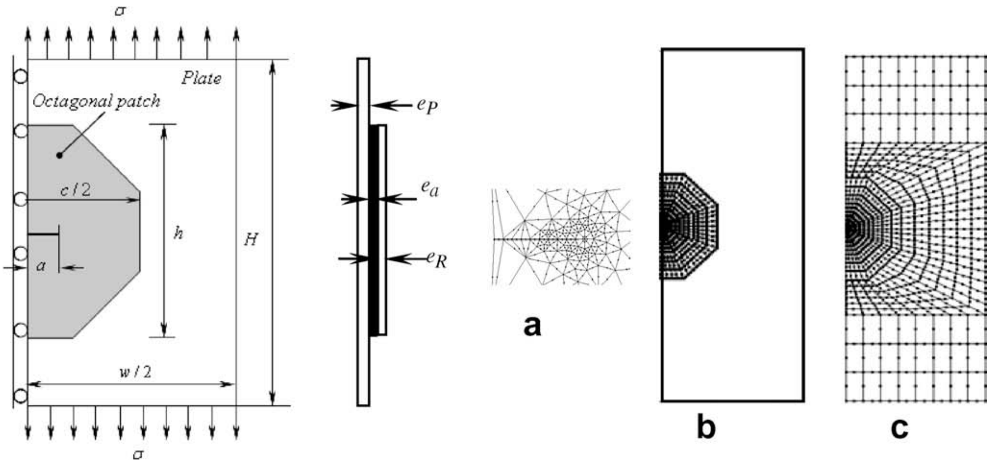

Fig. 1. Geometrical model and the structural meshing (a) centred crack, (b) patched crack, (c) meshing pattern.

the geometrical form of the plate as well as the loading, half the structure was needed.

3. Numerical analysis

Two-dimensional finite element code named FRANC2D/L (FRacture Analysis Code for 2-D Layered structure) was used in the numerical modelling. This code was originally developed at Cornell University and modified for multi-layers at Kansas State University, and is based on the theory of linear and non-linear elastic fracture mechanics [16]. In this study, the following assumptions were assumed in order to obtain the essential structural response features:

- Each layer was considered as an individual two-dimensional structure under a state of plane stress.
- The adhesive layer is homogeneous, linear, elastic and isotropic.
- The adhesive was supposed to deform only in shear and the deformation is uniform throughout the adhesive thickness.
- The surface shear transmitted through the adhesive is assumed to act as a surface traction on the adherents.
- The shear stresses in the adhesive are given by

$$\tau = \frac{G_a}{e_a}(u_1 - u_2) \tag{1}$$

where u_i are the displacements in layer 1 (plate) and layer 2 (patch), respectively.

The whole structure (plate and patch) was meshed using the standard eight noded serendipity elements with quadratic shape functions. These elements perform well for elastic analysis and have the advantage that the stress singularity at the crack tip can be incorporated in the solution by moving the eight nodes to the quarter-point locations [17]. Fig. 1 shows a typical mesh model of the plate, the patch and near the crack tip. The modified crack closure techniques were used to calculate the SIF.

4. Effect of patch material

The fracture parameters are influenced by the patch rigidity, the size of the attachment area and the adhesive resistance [15]. The patch materials influences directly the variation of the SIF. To highlight the repair process of a central crack, two patches having the same geometrical form but with different mechanical properties were chosen. The analysis consists in varying the length of the repaired crack while maintaining the same mechanical characteristics of the plate and patch.

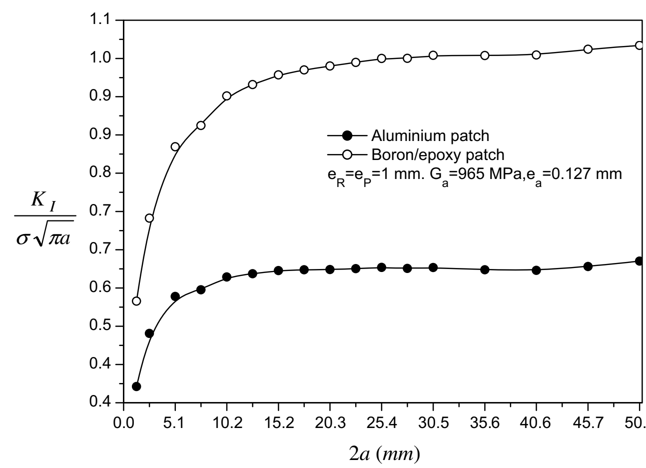

Fig. 2. Influence of the patch mechanical characteristics on the SIF variation.

Fig. 2 illustrates the effect of mechanical properties of the patch on the variation of the SIF. For small crack lengths ($2a = 10$ mm), the SIF increases rapidly. Beyond this length, the SIF converges towards a stable value. This convergence is however faster for a metallic patch. On Fig. 3, the variation of the dimensionless SIF reduction versus the crack length was represented. This factor is defined by

$$K^* = 1 - \frac{K_P}{K_u} \tag{2}$$

where K_P and K_u are the SIF for the patched and unpatched crack plate, respectively.

Fig. 3 indicates that the patch is of a great efficiency in reducing the crack growth. In comparison with the unrepaired cracked plate, the reduction of the SIF in mode I of the patched crack using a metallic patch varies from 46% to 89%. However for the case of a boron/epoxy patch, the SIF reduction varies between 25% and 75%. Therefore, the SIF reduction difference between the two different patches is about 25% [18,19]. This is due to the inadequate orientation of the composite patch fibres with regard to the crack growth.

5. Effect of the composite fibres orientation

To show the effects of the composite patch fibre directions on the central crack repair, two cases were considered. The first case