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The effects of disbonds on the stress intensity factor of aluminium panels repaired using composite materials

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Abstract

Bonded composite patching has been recognized as an efficient and economical method to extend the service life of cracked aluminum components. The stress intensity factor is considerably reduced by the bonded composite repair. In this work, the finite element method is applied to analyse the behavior crack emanating from semi-circular notch root repaired by a boron/epoxy composite patch. The stress intensity factor (SIF) was computed for cracks repaired using a composite patch, taking into account of the disbond. In this case, the increase of patch thickness reduce the negative effects of disbond. The maximal reduction of composite patch of orientation (1) is the order of 56% more important with regard to patch of orientation (2). The minimal SIF in the presence of the disbond is obtained when the crack length is the order of $2\rho_{ent}$. It reaches its value maximal for a crack length equal to $2\rho_{ent}/5$.

Keywords: Disbond effect; Notch; Semi-circular patch; Crack; Stress intensity factor (SIF); Finite element analysis

1. Introduction

Adhesive bonded patching is one of the most widely used repair techniques to cracked or damaged metallic and composite structures [1,2]. In this technique, a composite patch is bonded to the parent structure to reinforce the cracked zone [3] and to try to restore the structure to its original design specifications. This technique has successfully addressed some of the aging aircraft problems [1].

To extend the service life of aging aircraft, a repair method using composite patches to reinforce cracked aluminum components is promising because composite laminates are non-corroding, conformable, easy to fabricate and have high specific modulus and strength. A number of studies have investigated structures with bonded composite patches [4–13]. Baker [4] summarized his researches in Australia on the repair of cracked metallic aircraft components using advanced fiber composites, considering the selection of adhesive system and composite patch design.

The introduction of a defect into a component is mechanically worse than the consequence of the net section reduction and the increase of the load bearing. This effect is usually named notch effect. It is known that the notches are the main causes of crack initiation. This is why the use of the bonded composite repair can play a significant role in the improvement of fatigue life of the notched structures [6]. This improvement intervenes on the one hand, in the fatigue life initiation by the reduction of the stress concentration at the notch tip, and on the other hand in the fatigue life propagation by the reduction of the stress intensity factor at the crack tip [6].

With the increase in computational power, the use of the numerical method, especially the finite elements method, contributed considerably to the comprehension of the mechanical behavior of defects under patch repair. Among the authors whom used the finite element method for the study of the crack patching, we can quote: Ting et al. [14], Callinan et al. [15], Jones and Chiu [16], Turaga and

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Ripudiman [17], Chung and Yang [18], Schubbe and Mall [19] and Bachir et al. [20]. Most of the previous works considered central patched cracks.

The determination of the SIF at the crack tip is one of the possible means of analysing the performance of bonded composite patches. It is known that high strength adhesives are characterized by a weak shear modulus. In the case of repaired cracks, the objective is to transmit the maximum of the stress to the adhesive and consequently to the patch in order to reduce values at the crack tip. It is also known that a reduction of the adhesive thickness decreases the SIF; it means that lower adhesive thickness is desirable for repairing cracks [21]. The lower thickness well supports the transfer loads towards the patch but increases the risk of adhesive failure. To foresee this risk, it is necessary to consider a disbond. The scope of this paper covers studying the behavior of repaired cracks in aluminum sheets in mode I by the finite element method. This method gives with great accuracy the stress intensity at the crack tip. The effects of the adhesive properties and patch thickness have been studied by [14,22]. This study introduces the effect of disbonds.

2. Geometrical model

Consider a thin elastic aluminum plate with a semi-circular lateral notch having the following dimension: height $H = 203.2$ mm, width $w = 152.4$ mm, thickness $e_P = 1$ mm and notch radius $\rho_{not} = 12.7$ mm. Subscripts, P, r, a will be used to identify parameters corresponding to the plate, the reinforcing patch or the adhesive layer, respectively. Thus, E_P, E_r, will denote the Young's modulus of the plate and the reinforcement; G_a, the shear modulus of the adhesive, and e_P, e_r, e_a, the respective thickness. The plate is repaired by external semi-circular patch.

Table 1
Materials properties (plaque, patch and adhésif)

Property	Aluminum	Boron/epoxy	Adhesive
E_1 (MPa)	7.2×10^4	208×10^3	
E_2 (MPa)		25.4×10^3	
ν_{12}	0.33	0.1677	0.32
G_{12} (MPa)		7.2×10^3	965
G_{13} (MPa)		7.2×10^3	
α (10^{-6} C^{-1})	22.7	4.5	50.0

The plate is subjected to tensile loading giving a remote stress state of $\sigma = 120$ MPa. A crack of length a emanating from the notch root and perpendicular to the loading direction is assumed to exist in the plate. The material composite patch is used for the reinforcement of the crack emanating to the semi-circular notch (see Fig. 1). The dimensions of the patch are: radius $\rho_r = 4\rho_{not}$ and thickness $e_r = 1$ mm. The material properties of the patch and plate are regrouped in Table 1. The stress plane conditions are assumed. Fig. 1 shows the geometrical model of the structures.

3. Numerical studies

A two-dimensional finite element code named FRacture Analysis Code for 2-D Layered structure (FRANC2D/L) was used in the numerical modeling work. 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

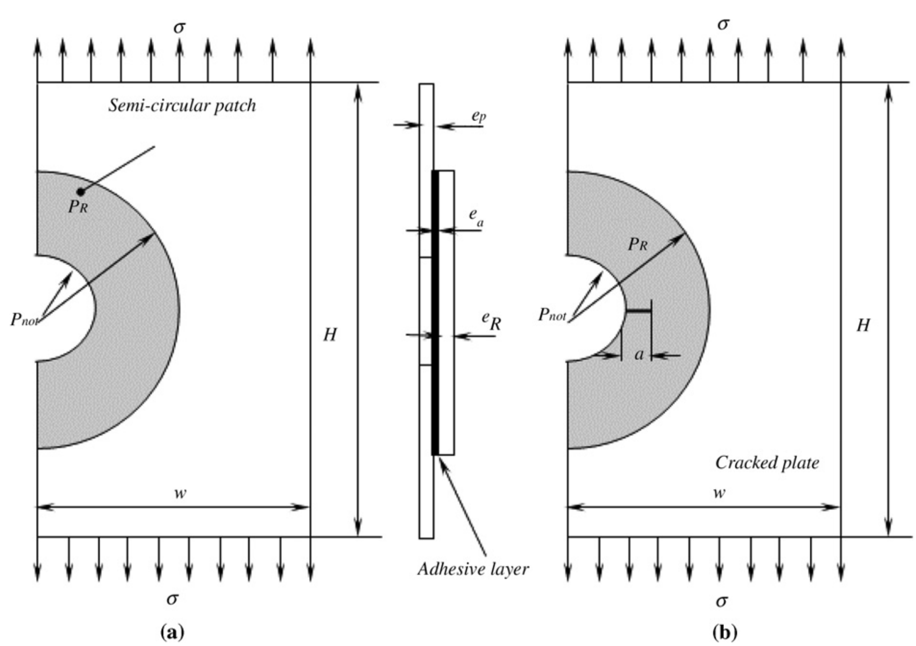

Fig. 1. Specimen details—cracked plate, adhesive and patch. (a) Notch without crack, (b) notch with crack.