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Edge-cracked stiffened panels analyzed by caustics

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Abstract

Externally bonded composite patches have been proven to be an effective method for repairing damaged aircraft structural components. They are ease in application and provide excellent in-service performance. The major function of a repair is to reduce the stress intensity factor at the crack tip. Calculation of stress intensity factor of a repaired crack has been performed by analytical and numerical methods. However, these methods are based on simplifying assumptions regarding material behavior and repair conditions. In the present paper an experimental determination of mode-I stress intensity factor (SIF), K_I, at the tip of an edge-crack or a V-notch reinforced with double bonded strips or with compression pre-stresses applied along the crack surfaces is undertaken by using the optical method of caustics. This method is simple in its application and has successfully been used for the solution of a host of crack problems of engineering importance.

1. Introduction

Composite patch repair is a recent method of repairing damaged aircraft structural components. The basic principle of the method is to adhesively bond a composite patch over the damaged area in order to restore the load carrying capacity of the structure. The method of composite patch repair presents many advantages over the traditional method of using metallic patches, such as, no fastener holes for patch application are needed, and therefore, no microcracks develop, a uniform stress transfer results, no drilling is necessary, and the time and cost for the repair are substantially reduced. For the calculation of patch dimensions analytical and numerical methods based on Rose' equations and finite element or boundary element analysis, respectively, have been developed.

Reinforcement of cracks with stiffeners or pre-stresses reduces the stress intensity factor at the crack tip and increases the lifetime of structural components by suppressing crack propagation. The reinforcement takes place with double or one-sided patches. Reinforcement with pre-stresses introduces compressive loads, so that the crack propagation is suppressed. Many researchers have

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studied crack reinforcement problems by analytical and numerical methods [1–4]. However, these methods are based on simplifying assumptions regarding material behavior and conditions of repair.

In the present paper the reinforcement effect of stiffeners or pre-stresses on the stress intensity factor at the tip of cracks or notches is studied by the optical method of caustics. This method has successfully been used in the past for the determination of stress intensity factors in crack problems [5–7]. The method is characterized by the simplicity of its application and the accuracy of its results. The specimen is illuminated by a coherent light emanated from a lazer light beam and the reflected or transmitted rays from the vicinity of stress singularity are concentrated along a highly illuminated surface in space. When this surface is cut by a viewing screen a caustic curve is obtained. By measuring characteristic dimensions of the caustic the stress intensity factor is obtained. Even though the method has been applied so far to specimen sizes of the order of centimeters it can also be extended to smaller specimens at the micro-scale level by using a lazer beam of micro-order diameter. Such lazers are available today.

2. Specimens

Six specimens subjected to uniaxial tension were examined. Three of them had a transverse edge-crack (Fig. 1(a)) and three had an edge-V-notch (Fig. 1(b)). The type of reinforcement used was: (a) Stiffener-strips placed at the middle of the crack or notch on both sides of the specimen, and (b) compression pre-stresses at the tip of the crack or notch applied with plugs at the boundary of the specimen (Fig. 1). More precisely, pre-stress is applied on the boundary of the crack through two plugs and a tendon which is attached to the plugs. The experimental method of caustics was used for the determination of K_I for both plain and reinforced specimens.

3. Caustics at crack tip

The deviation vector, **W**, of a light ray reflected from a point P located on the rear face of a specimen in the neighborhood of a crack tip is given by [5–7]:

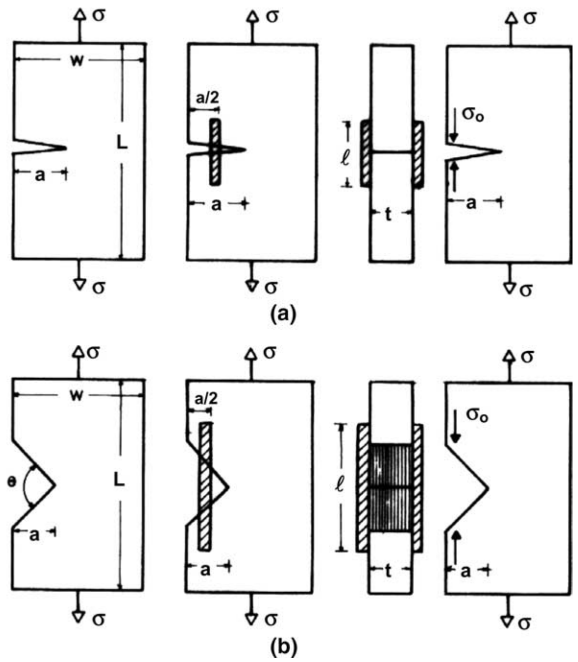

Fig. 1. Geometry of an edge-cracked (a) and an edge-V-notched specimen (b) with double-sided strip reinforcements.

$$\mathbf{W}_r = X_r\mathbf{i} + Y_r\mathbf{j} = \mathbf{r} + \mathbf{w}_r \quad (1)$$

with

$$\mathbf{w}_r = -2z_0 t c_r \,\mathrm{grad}(\sigma_1 + \sigma_2) \quad (2)$$

where c_r is the optical constant of the material for light rays reflected from the rear face of the specimen, z_0 is the distance between the specimen and the reference screen where the caustic is formed, t is the thickness of the specimen and σ_1 and σ_2 are the principal stresses in the vicinity of the crack tip. We have [8]

$$\sigma_1 + \sigma_2 = 4\mathrm{Re}\Phi(z) \quad (3)$$

where $\Phi(z)$ is the complex stress function and z is the complex variable ($z = x + iy$). The equation of the generatrix (initial) curve of the caustic located on the specimen is given by

$$|4C_r\Phi''(z)| = 1 \quad (4)$$