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Review

Influence of water ingress onto the crack propagation rate in a AA2024-T3 plate repaired by a carbon/epoxy patch

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ABSTRACT

The objective of this study is to analyze by experimental tests, the effect of hygrothermal aging of the patch and the adhesive on the fatigue behavior of a damaged 2024-T3 aluminum plate repaired by a carbon/epoxy patch composite. The effect of the water absorption by the composite patch and the adhesive has a significant effect on the load transfer from the damaged plate and therefore on the delay of the crack propagation. The more water immersion time is important, the less is the fatigue strength of the repaired structure. The experimental results showed that the number of cycles to fracture is directly related to the aging time.

1. Introduction

Fatigue has been a potential problem for structures subjected to repeated loads over their life time. All repeated loads e.g. vibrations of a structure, rotation of a crank shaft of engines, etc. can potentially cause fatigue failure.

Repair by composite bonding is an efficient and cost effective method to extend the fatigue life of cracked components in aerospace structures [1]. The evaluation of fatigue crack growth behavior of cracked panels repaired by composite patch has become a topical subject in this research area. Several analytical and experimental studies were done to analyze the fatigue crack growth behavior in metal structures repaired composite patch [2–7]. Repair patches were manufactured to minimize the stress and deformation fields in the damaged area through the adhesive [8–12]. In a repaired structure by patch, the stress intensity factor at the point of the crack is reduced to the minimum thereby increasing the lifetime of the structure. The crack propagation rate is an important parameter to consider in the design of aerospace structures in order to evaluate the durability of the structures. Many laws have been proposed to describe the evolution of the propagation of fatigue cracks, but the phenomenological law proposed by Paris remains the most used by engineers. This law relates the cracking rate to the stress intensity factor variation by a power law:

$$\frac{da}{dN} = C(\Delta K)^m$$

where C and m are two parameters of the material defining, respectively, the position and the slope of the line of Paris. They are determined by basic experiments on specimens and they depend strongly on the material properties.

Mechanical stress associated with the humidity are the main factors of the assemblies damage, affecting directly the intrinsic properties of the materials, and/or reducing greatly the adhesion properties at the interface [13,14].

The aim of our work is to analyze by fatigue testing the behavior of an aluminum AA2024-T3 plate in the presence of a crack emanating from a side notch, repaired and not repaired by a patch composite, and to study the effect of aging in water at ambient temperature onto the fatigue behavior of repaired structures. C and m of Paris law parameters were determined as a function of the immersion time.

2. Experimental procedure

2.1. Materials

We consider a AA2024-T3 aluminum alloy plate, which is a common material used in aeronautic applications. The plate has an

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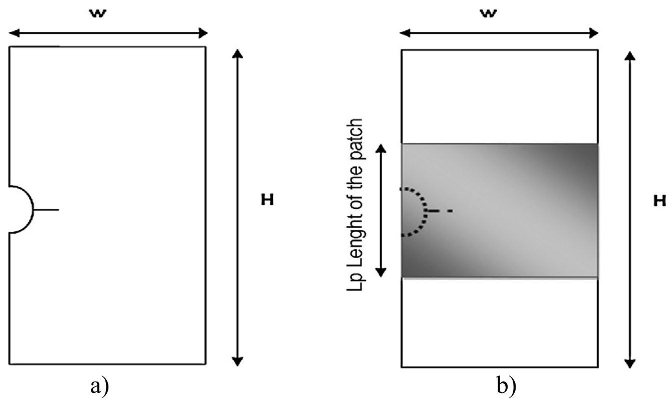

Fig. 1. Geometric model of the aluminum plate a) unrepaired and b) repaired by composite patch.

initial 5 mm length crack emanating from a lateral circular notch. This plate is repaired or not (Fig. 1) by bonding a carbon/epoxy patch composite with ADEKIT A140 adhesive The adhesive used is a bi-component structural epoxy (AXSON company) based on a modified epoxy resin. This adhesive is in the form of two viscous liquids packaged in 50 ml and 400 ml cartridge and it requires the use of a manual or pneumatic gun for application. The ADEKIT A140 adhesive has a good mechanical performance at temperatures up to 180 °C and can support short exposures to 215 °C. The mixture of the epoxy resin (two-component) is carried out shortly before the assembly: the period between the preparation of glue and its application does not exceed 30 minutes.

Composite used for repair is a carbon–epoxy laminate, composed of two kind of carbon fiber unidirectional, high modulus and high strength; and of an epoxy resin. The designation of this composite is Hexply type: X700/epoxyde and M40J/epoxyde.

The thickness per ply is 0.358 mm and composite plates are obtained by successively stacking 5 plies, for which the stacking sequence is as follows: [0°; 90°; 0°, 90°, 0°], all plies are with high strength except a middle ply is with high modulus.

The first ply is 0°, where zero degree direction is perpendicular to the crack and parallel to the applied load. Indeed, previous works have shown that to have a good transfer of the load from the damaged area to the composite patch, it is recommended that the first ply of the composite, adjacent to the damage surface, should be with 0° fibers [15].

The dimensions of the various materials are shown in Table 1.

Tensile tests (Fig. 2) were conducted on aluminum and adhesive specimens, to obtain their mechanical properties, which are shown in Table 2.

These mechanical properties will be used to determine analytically the stress intensity factor.

Table 1
Dimensions of the various materials of the unrepaired or repaired systems.

Dimensions	Aluminum plate	Adhesive	Composite patch
H (mm)	100	50	50
w (mm)	50	50	50
e (mm)	2	0.125	1.85

Table 2
Mechanical properties of the different materials.

Mechanical properties	AA 2024-T3	Patch carbon/epoxy	Adhesive ADEKIT A140
E_1 (GPa)	72	78	2.69
E_2		43	
E_3		43	
ν_{12}	0.32	0.17	0.3
ν_{13}		0.17	
ν_{23}		0.04	

2.2. Calculation of the rigidity of the structure

The calculation of the stiffness of the patch is necessary because the patch has a very important role for absorption of the stresses from the damaged plate. The rigidity of the assembly ratio is given by the

$$S = \frac{E_r e_r}{E_p e_p} \tag{1}$$

where e_r, E_r: thickness and Young's modulus of the patch; e_p, E_p: the thickness and Young's modulus of the plate.

The ratio of stiffness should be between $1.0 < S < 1.5$.

In our case, the composite patch type carbon/epoxy has a thickness of 1.85 mm and a Young modulus $E_r = 78000$ MPa, and the aluminum plate is about 2 mm thick with a Young modulus $E_P = 72000$ MPa, then the rigidity of the assembly is:

$$S = \frac{78000 \times 1.85}{72000 \times 2} = 1.00$$

2.3. Surface preparation

An important element in the realization of bonded joints is the surface treatment of substrate surfaces. Many studies have been accentuated on the influence of surface treatment on the mechanical behavior of bonded assemblies [15,17].

The aluminum plates to be repaired are undergone a surface treatment which includes

- cleaning and degreasing with acetone or ethanol;
- drying;

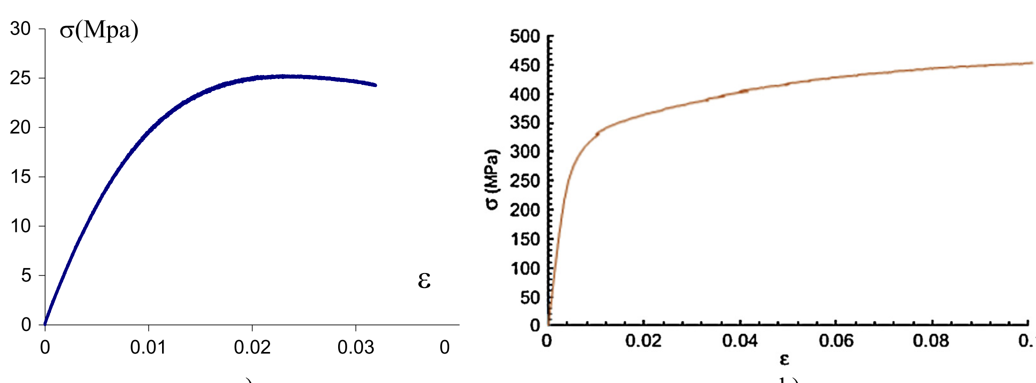

Fig. 2. Tensile stress–strain curve for: a) Adhesive ADEKIT A140, b) Aluminum plate [16].