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Experimental analysis of the fatigue life of repaired cracked plate in aluminum alloy 7075 with bonded composite patch

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ABSTRACT

In this study, we analyzed the fatigue behavior of a V-notch crack in an aluminum alloy 7075-T6 plate repaired with bonded composite patch under constant and stepped variable amplitude loading. The effect of adhesive disbond on the repair performance was analyzed. The obtained results confirm the need of repairing cracks at their early creation for a maximum repair performance and showed that the increases in the disbond width and the stress ratio have a large negative effect on the repair efficiency. The latter is low for increasing loading blocks but significantly high for decreasing blocks.
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1. Introduction

Bonded composite repair of aircraft structures was developed by Dr. Alan Baker and his team in 1972. The technology involves adhesively bonding patches of advanced fiber composite materials to repair damaged aircraft structures and to stop stress corrosion cracking. The repairs are structurally very efficient, can be applied rapidly and are cost effective. The technology has many advantages over traditional mechanical repair methods, such as bolting or riveting. Composite patches are lighter, offer more uniform load transfer, seal interfaces reducing corrosion and leakage, create minimal damage to the parent structure and facilitate non-destructive inspections. Since aircraft structures are often subjected to fatigue loading condition, analysis of the fatigue behavior for composite patches repair is thus essential to evaluate the repair performances. Several studies were carried out to analyze the improvement of the fatigue life of repaired structures compared to unrepaired structures [1–8]. Bonded patch repair reduces stresses near the crack by transferring stresses between the cracked structure and the composite patch throughout the adhesive layer, and therefore retards the crack growth. Jones and Chiu [9] showed that externally bonded composite repairs can be successfully used to extend the fatigue life of thick structural components. Hosseini-Toudeshky [10] analyzed the effect of the number of plies of the composite on the repair performance and concluded that the life of a cracked panel of 2.29 mm thickness may increase by about 65% and 236%, by implementing a 4 and 16 layers patch, respectively. However, for 6.35 mm thickness, the life of repaired structures may be improved by only 21–35% according to Hosseini-Toudeshky [10]. Aakkula and Saarela [11] analyzed the effect of the stiffness ratio between the aluminum structure and carbon/epoxy and boron epoxy patches on the repair performance. They showed that this ratio has a significant effect on the fatigue life of repaired structures. Indeed, and according to the results of Aakkula and Saarela [11],

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Nomenclature

a	crack length
F	load
ΔF	difference between maximum and minimum amplitude of fatigue loading
N	number of fatigue cycles
R	load ratio
w	specimen width
W	disbond width
L	disbond length

the fatigue life improvement, for center crack repaired with single-sided patch, was better with the wet-laminated carbon/epoxy having a stiffness ratio of 1.04. For edge-cracked specimens the best repair performance was achieved with the double-sided boron/epoxy repairs having a stiffness ratio of 0.65. Wang et al. [12] conducted experimental fatigue tests on notched AA7075 and AA6061 substrates in the gigacycle regime, with and without boron–epoxy patches of 1-ply, 2-pliesand 4-plies. They observed that the patch repair improves the fatigue life of the substrate considerably. In addition, Wang et al. [12] concluded that the improvement in the fatigue strength with a 1-ply patch is not significant while it is improved nearly 100 times with 4-plies patching. Mall and Conley [13] investigated the fatigue behavior of repaired crack in thick and thin panels. They observed that, due to the asymmetric repair there was a significant bending moment causing anon-uniform crack growth between the un-patched and patched faces of the repaired thick panels. This moment is negligible for thin panels [13]. Chung and Yang [14] analyzed the behavior of inclined crack repaired with bonded composite patch by conducting fatigue tests. Their results showed that the fatigue life of patched plate with inclined crack increased approximately 2.4–5.0 times compared to the un-patched plate. According to Chun and Yang [14] the maximum effect of the patch was obtained for a 0° crack inclination (pure mode I) and the effect was relatively weak for a 45° inclined crack.

The adhesive disbond during the repair process has recently attracted some attention in the literature. Several papers describing the effects of the adhesive disbond on the repair efficiency were published [14–20]. Bachir Bouiadjra et al. [21] analyzed the effect of adhesive disbond on the performance of bonded composite repair in aircraft structures. They showed that adhesive disbond significantly reduces the repair efficiency by increasing the stress intensity factor at the crack tip. Bachir Bouiadjra et al. [21] conducted a numerical investigation on the effect of the disbond width (normal to the rack) and length (parallel to the crack) on the repair efficiency. It was shown that the increase of the disbond width significantly increases the stress intensity factor at the tip of repaired cracks which drastically reduces the repair efficiency, however, the effect of the disbond length is not significant. Ouinas et al. [22] investigated numerically the behavior of a cracked aluminum plate repaired with an adhesively bonded composite patch under a full length disbond. They confirmed that the reduction of stress around the crack tip increases with the patch thickness for a disbond width higher than the crack size.

Many of the structures that utilize adhesive bonding are subjected to variable amplitude loading. It has been well documented that fatigue life of metals is affected by the load history. In order to obtain accurate fatigue life predictions, we need to take into account the effect of the load amplitude variation. In this work, we hypothesize that the loading variation affects the crack growth of bonded structures. So far, the available research on variable amplitude loading of adhesively bonded joints is quite limited when compared to the studies conducted on constant amplitude loading.

In this study, we evaluated the repair efficiency by analyzing experimentally the fatigue life of repaired V-notched aluminum plate under constant and variable amplitude loading. The effects of the initial crack length of patching and the adhesive disbond on the repair efficiency were highlighted.

2. Experimental setup

2.1. Specimen details

In this research, we conducted fatigue tests on unrepaired and repaired single edged notched tension (SENT) specimens (see Fig. 1). The specimens, of dimensions 150 × 50 × 2 mm, were cut from Al 7075-T6 plates. An initial v-notch of 6 mm depth and 60° angle was created in the center of each specimen by milling, as shown in Fig. 1, according to ASTM E647 standards [23]. The specimens were then pre-cracked to different initial crack lengths under fatigue loading. The presence of the V notch facilitates the mode I propagation of the crack. Once the desired crack length is reached, the sample was unloaded and taken for surface preparation followed by bonding the patch.

2.2. Patch preparation

Composite patches are made with 8 plies of unidirectional carbon/epoxy pre-pregs. The dimension of each ply was 250 × 250 mm. After laying up, the laminate was cured under a hot press at 120 °C for 90 min. The pre-pregs were

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