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Fatigue Behaviour of AA 7075-T6 Plates Repaired at Different Crack Lengths

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Bonded Composite Repair Technology (BCRT) is widely used to reinforce weakened cracked components and damaged metallic structures in various aerospace applications. In this work, the fatigue crack behaviour of V- notched aluminium 7075-T6 plates, of 2 mm thickness, bonded with “single side” carbon composite patch configuration was experimentally investigated. The repair efficiency and fatigue life of cracked specimens repaired at different initial crack lengths of (a_0 = 3 mm, 6 mm and 9 mm) and different stress ratios of (R = 0 and R = 0.1) were investigated. The results obtained showed that the bonded patch increases the fatigue life of all repaired samples ranging from 2.2 folds for 9 mm to 4.3 folds for 3 mm initial crack lengths. Repair can be treated at any level of crack initiation but preferably should be conducted as soon as it is detected. Stress ratio and initial crack lengths affect the repair efficiency. This is clearly manifested in the extended life and load carrying capacity of adhesively bonded specimen.

1. Introduction

The advanced Bonded Composite Repair Technology (BCRT) is widely used to reinforce damaged metallic structures in various applications, particularly for repair of aging aircrafts in aerospace industries. It offers significant advantages over conventional repair methods (Baker et al., 1999). Due to high demand, this technology has been receiving substantial attention. In the last few decades, many studies have investigated this technique, both numerically and experimentally, for different materials and different specimens' configurations. Baker (1997) proposed the bonded repair technology and concluded that it can improve the fatigue life significantly. Sabelkin et al. (2006) used stiffners along with composites to repair the damaged panels. Khan et al. (2014) investigated the parametric effect of composite and metallic patches on the repair performance of the damages structures. Albedah et al. (2013) proposed the analytical solution of stress intensity factor (SIF) for cracks emanating from central holes repaired with bonded composite patch. Most of these early investigations were carried out on thick aluminium plates (Schubbe and Mall, 1998). Soutis and Hu (1997) suggested that reducing the patch thickness near the edges decreases the stress concentration in both shear and peel stresses. Albedah et al. (2011) studied numerically the effect of single and double sided patching on the repair performances. They used three dimensional finite element methods to compute SIF and concluded that double patch leads to significant decrease in the SIF. Bachir et al. (2011) studied numerically the effect of patch shapes on repair efficiency of thin aluminium plates. They concluded that SIF decreases significantly for the repaired specimen which is beneficial for fatigue life. The important parameter involved in repair efficiency is the amount of damage present i.e., the initial cracks. The effect of initial crack size on the repair efficiency in thin aluminium plates is not adequately and systematically addressed. Very few scattered works on this issue are reported by Hosseini-Toudeshky (2006).
Yu et al. (2012) conducted experimental fatigue tests on steel plates with centre holes and different initial crack lengths. He concluded that the strengthening method is useful for all stages of crack propagation and it seems better to repair as early as possible. Mello et al. (2005) analysed the repair performance of Al 5052-

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H32 by composite patch for different initial crack lengths. They also conducted experiments for different plate thickness of 4 mm and 6.5 mm. Their results showed that reinforcement of composite patches increases the fatigue life significantly and the fatigue life is inversely proportional to crack growth rate. Mello et.al (2005) concluded that the repair is affected by the initial damage and repair can be treated at any level but preferably should be repaired as soon as it is detected.
In this work, the effect of initial crack length on the fatigue crack behaviour of V-notched aluminium 7075-T6 plates, of 2 mm thickness, bonded with "single side" carbon composite patch configuration was experimentally investigated. A complete comprehensive and systematic experimental program is conducted on the effect of initial crack lengths of 3 mm, 6 mm and 9 mm on the repair efficiency for thin aluminium plates (Al 7075-T6), subjected to fatigue loading at different stress ratios of R = 0 and R = 0.1. The single side repair is employed in this investigation. This is advantageous when it is not possible to access both sides of a weakened structure. In single side repair, disassembling of structure is not needed.

2. Materials and Experimental Techniques

2.1 Specimen Preparation

The experimental program conducted in this study includes constant amplitude fatigue tests on unrepaired and repaired single edged notched tension (SENT) specimen. Specimens were prepared from thin aluminium 7075-T6 plates of 2 mm thicknesses. The sheet was cut into dimensions of 150 mm × 50 mm × 2 mm. Then, v-notch of 6 mm depth at 60° angle was cut in the centre of each specimen by milling according to the ASTM E647 standards (International, 2011) as shown in the Figure 1. The specimens were polished to remove the indentations formed, if any, during the cutting process. The specimens were then pre-cracked to three different initial lengths of a_0 = 3 mm, 6 mm and 9 mm from the notch tip. The pre-cracking was accomplished by cycling the specimens at a maximum stress of 70 MPa and 20 Hz frequency. This pre-cracking process was accomplished to ensure that the effect of the machined starter notch is removed. Once the desired crack length is reached, pre-cracking was stopped. Then, the specimen was cleaned and the composite patch is adhesively bonded on the cracked area (see Figure 2). Material properties for the plate and composite patch are shown in Table 1.

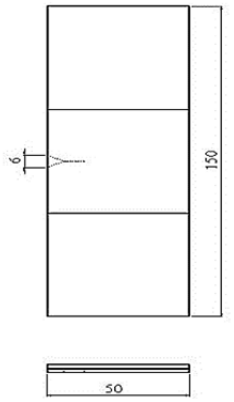

Figure 1: Specimen and patch details

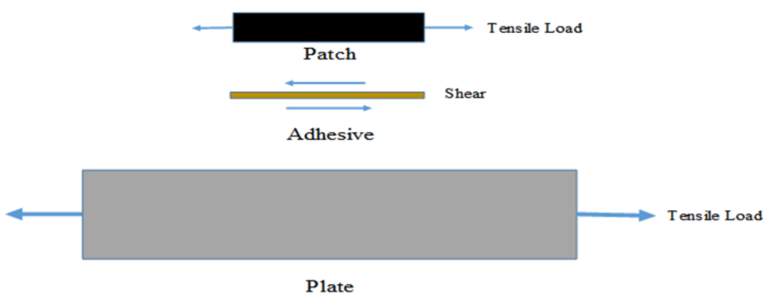

Figure 2: Specimen and patch details

Table 1: Material properties

Properties	Materials		
	Al 7075-T6	Carbon/Epoxy	Adhesive (Araldite)
Longitudinal Young's Modulus (GPa)	71.7	130	2.52
Transversal Young's Modulus (GPa)	71.7	9	2.52
Longitudinal Poisson Ratio	0.33	0.25	0.32
Transversal Poisson Ratio	0.33	0.25	0.32

2.2 Patch Preparation

Patches were made of unidirectional carbon/epoxy pre-pregs of different layers oriented at zero degree one over the other. The prepregs were then cured at 120 °C for 90 min in a hot press as recommended by the provider. Square shaped patches of 50 mm × 50 mm, laid with 8 plies were used to patch the cracked aluminium panels. The surface of SENT specimens was prepared using Bell Process Specification method (Wegman and Twisk, 2013). The pre-cracked specimens were repaired with the composite patches bonded to the specimens using the adhesive araldite such that the lay-up principal direction is along the loading direction.

2.3 Test Procedure

Please Fatigue experiments were carried out on a 100 kN capacity Instron 8801 servo hydraulic machine. The experimental setup used is shown in Figure 3. All tests were performed at room temperature using a sinusoidal waveform at a loading frequency of 20 Hz. The SENT specimens, both unrepaired and repaired, were loaded cyclically at two different stress/load ratios of R = 0 and R = 0.1 with a maximum stress of 70 MPa.

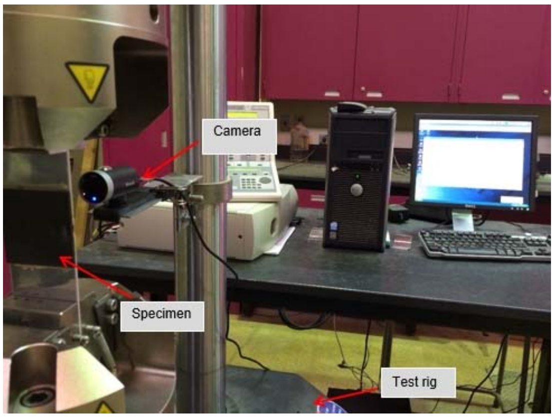

Figure 3: Experimental setup

The specimens were pre-cracked to different lengths before repairing with composite patch. The pre-cracking was accomplished by cycling the specimens. It was done to ensure that the effect of the machined starter notch is removed. All samples were cured under constant pressure and temperature conditions to ensure the adhesive quality, constancy and thickness. The samples were cured under a hydraulic press to maintain the pressure constant at room temperature. Three samples at least were tested for each condition to ensure the result constancy and accuracy. For each test, the number of cycles with respect to crack length was recorded using high-speed camera for later processing. Then, the data obtained was processed to produce the fatigue behaviour plots of the samples as displayed in the results section.

3. Results and Discussion

3.1 Fatigue tests

The results obtained from the tests on repaired and unrepaired specimen in L-T direction, subjected to constant cyclic loading with maximum stress of 70 MPa were processed first for extracting the values of crack length (a) and the number of cycles (N) as presented in Figure 4. All the tests were repeated at least three times to observe the consistency and an average presented curve is plotted for each test configuration and condition. A difference of less than 10 % was observed in the fatigue lives, which is within the normal acceptable range. Fatigue life and fatigue crack growth rates (FCGR) of unrepaired and repaired plates are obtained by processing the experimental results. Then, these are plotted in Figures 5 to 8 for all samples tested. It is evident from these figures that the fatigue life of repaired aluminium plates is much higher than the unrepaired ones. It is in accordance with the results found in the literature (Seo, 2002). Figure 4 shows the effect of fatigue life of unrepaired (UR) and repaired specimen for the different initial crack lengths of 3 mm, 6 mm and 9 mm at two stress ratios (R = 0 and 0.1). It is observed that for an initial crack length of 3 mm, the fatigue life is maximum, and is more than 3 folds compared to unrepaired specimen. However, for an initial crack length of 9 mm, the fatigue life has increased to less than two folds of unrepaired configuration. As the crack length increases, the fatigue life is decreasing asymptotically. The initial crack length of 3 mm has been adapted in this investigation.

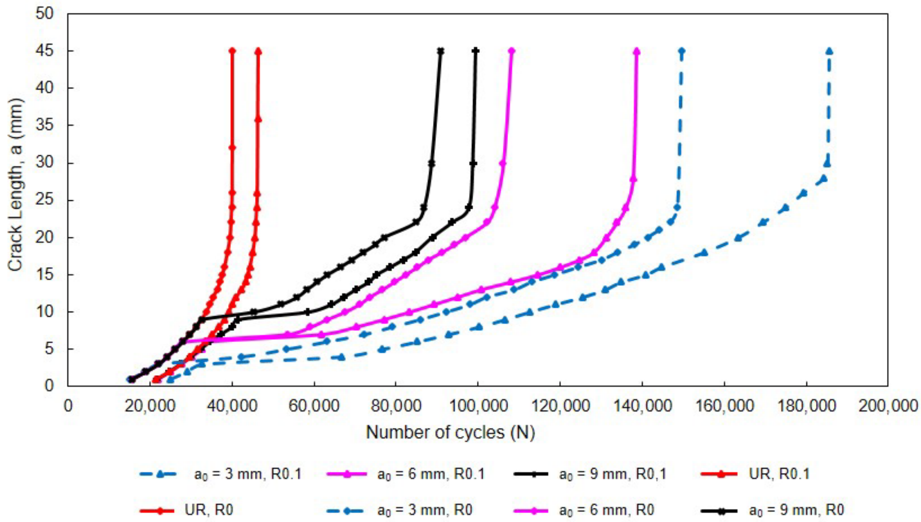

Figure 4: Initial crack length effect on fatigue life for stress ratios R0 and R0.1

3.2 Crack Growth Rates

Figures 5 to 8 display the fatigue crack growth rates variation with crack length for both unrepaired and repaired specimens. These log plots were derived from the experimental data obtained from tests of patched and unpatched samples with initial crack lengths of 3 mm, 6 mm and 9 mm. The data fitted with linear regression, which matches with Paris law, are shown in the figures. For all tested specimens, it is clear from the plots that the rate of fatigue crack growth is higher for unrepaired specimen. The difference between the unrepaired and repaired curves tends to be higher as the initial crack length increases. This is clearly shown in Figures 5 to 7 that the difference between the curves tends to be more pronounced as the initial crack length is increased as displayed in Figure 7. This indicates that, for initial crack length of 9 mm or more, the repair is not quite efficient (Figure 8).

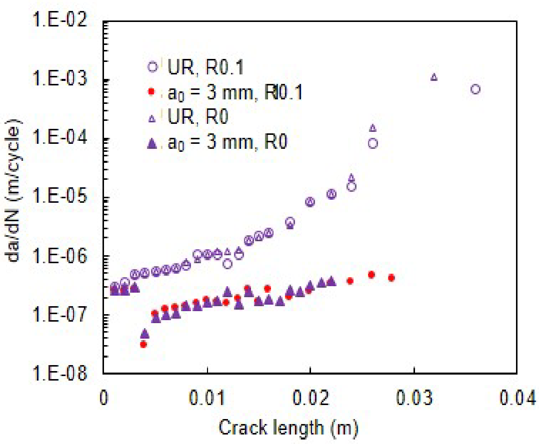

Figure 5: FCGR of unrepaired and repaired for a_0 = 3 mm specimen

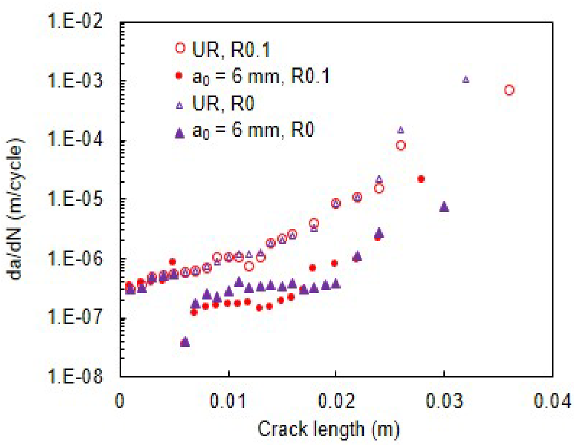

Figure 6: FCGR of unrepaired and repaired for a_0 = 6 mm specimen

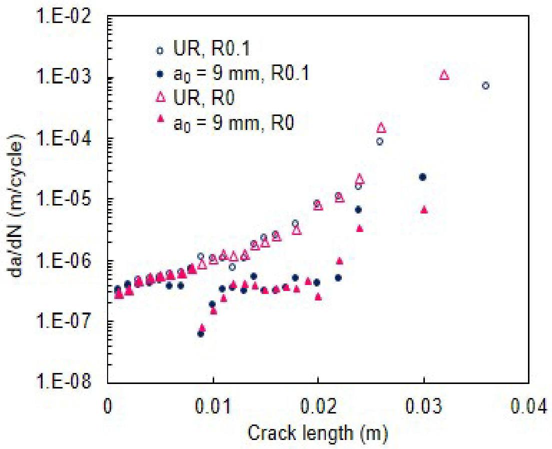

Figure 7: FCGR of unrepaired and repaired for a_0 = 9 mm specimen

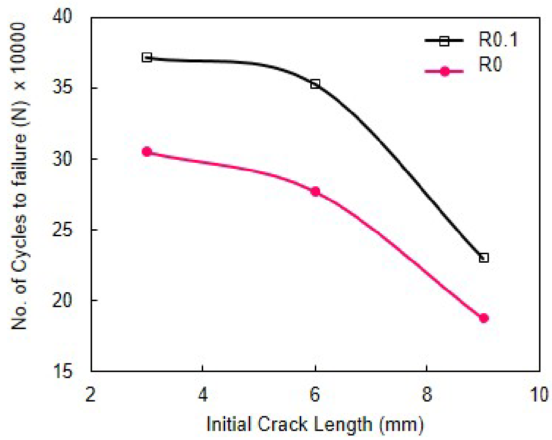

Figure 8: Initial crack length effects on the fatigue life of patched crack plates loaded at two stress ratios

4. Conclusions

Fatigue crack growth behaviour of cracked aluminium 7075-T6 plate with bonded composite patch repair was experimentally investigated. The fatigue behaviour of 2 mm thin SENT specimens repaired with unidirectional carbon/epoxy patch using Araldite adhesive has been investigated. The main conclusions drawn from this study are:

1. The strengthening method is useful for all stages of crack propagation based on the experimental results obtained.
2. The crack must be repaired as soon as it is detected.
3. The fatigue life for bonded patch increases almost four folds for 8 plies patches with an initial crack length of 3 mm.
4. Fatigue crack growth rates (FCGR) were higher for unrepaired specimen.
5. FCGR reveals beneficial effect of composite patch even for thin plate to extend the life of the damaged or weakened structure.

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