ADHESIVE EFFECT ON THE PERFORMANCE OF THE REPAIR EFFICIENCY OF BONDED ALUMINUM ALLOY

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Abstract—Aircraft cracked structures life can be extended with the reinforcement of composite and metallic patches using bonding techniques. Effect of the adhesive on the performance of the patch repairs was evaluated by conducting a comparative study on cracked aluminum plates. Fatigue tests were conducted on 2 mm thick specimens under a maximum surface load of 120 MPa for both repaired and unrepaired specimen configurations at stress ratios of R= 0 and R= 0.1 using 20 Hz frequency. The fatigue life of the specimen is affected by the stress ratio in both cases i.e. patched and unpatched case. As the load ratio increases, the fatigue life increases for both repaired and un-repaired specimen. A numerical study of some tested configurations has been conducted using Franc2D. The numerical results for unpatched cases are in good agreement with the available analytical solution. It can be observed from the numerical investigations that there is a drastic reduction in SIF after specimen reinforcement. The maximum observed reduction in SIF after patching was around 65%.

Keywords—Crack length (a), Stress ratio (R), Stress intensity factor (SIF).

I. INTRODUCTION

Cracked structures repaired with bonded patches have become a realistic solution to extend the service life of the aircraft fleet over the last few decades. This type of repair has several advantages over the conventional methods like that of bolted repairs as it cause minimal alteration to the aerodynamics and good formability to complex structures. Several studies [1–5] have been conducted in the recent years to assess the effects of some of the above mentioned design factors on the performances of bonded repairs. Adhesive properties play a vital role in repair technology and that is the main reason of focus in the literature.

In the literature adhesives properties have a particular importance. Gkikas et al. [1] introduced small weight fraction of multiwall carbon nano-tubes in a polymer adhesive film used for bonded repair. Results from the experiments they got shows that this reinforced adhesive be employed as a reinforcing/mediation in order to allow the widespread use of bonded repair with carbon fiber reinforced composites. Effect of the patch was studied by BachirBouiadjra et al. [2] by patching the metallic structures with rectangular and trapezoidal shapes. Durability and efficiency of the trapezoidal shapes is far better than the rectangular one. Ramji et al. [3] conducted experiments on several patch shapes and they concluded that the extended octagonal patch shape performs better in case of stress intensity factor reduction. Hosseini et al. [4] concluded that with the increase in thickness of the composite patch, fatigue crack propagation of repaired stiffened panel is also increased. Aminallah et al. [5] used the finite element method to estimate the intensities of the thermal stresses in bonded composite repair of aircraft structures, they concluded that these stresses lead to an increase of the stress intensity factor what cause the reduction of the fatigue life of the repaired structures.

A considerable amount of research on crack-tip stress intensity analyses have been conducted by many researchers. Repair of aluminum structures using composite material was initiated by Baker in the early 1970s [6]. Following that researchers purposed different numerical techniques for stress analysis and subsequent derivation of stress intensity factor of the repaired panels. For instance, Sun et al. [7] developed a finite element model for analyzing the stress distribution and stress intensity factor of cracked plates repaired with a single-side patch. Jones et al. [8,9] studied the theoretical and design aspects of the repaired panels. They used finite element method based on the displacement field and assumed a shear stress through thickness profile adopted in the development of a patch element. Baker [10] also studied the fatigue crack propagation of centrally cracked aluminum panels repaired with boron/epoxy composites.

The aim of this study is the analysis of the behavior of a crack reinforced in an aluminum plate in mode I using the finite element method. The composite patch under analysis is the boron/epoxy which had been used successfully in aeronautical repair. Various authors [11,12] showed that in practice the parameters influencing the performance of the repair are the properties of both the patch and the adhesive. For this purpose, the effects of the adhesive shear modulus, its thickness as well as the thickness of the patch on the variations of the SIF of a composite patch are examined in the literature.

II. EXPERIMENTAL WORK

The materials examined in this study (Al 2024-T3) are widely used in aeronautical structures. The fatigue tests were performed in a load controlled mode using servo hydraulic INSTRON machine (model 8801) of 100 kN capacity and following the ASTM E647 [13] standard. Digital camera and visual observations were

used to monitor the crack growth. The single notched specimens of 150x50x2 mm3 size (Figure 1) have been gripped on an area of 25x50 mm2 from each side and subjected to a constant amplitude fatigue loading. Observations were recorded for the patched (longerlasting tests) and unpatched specimen by using a digital camera as shown in Figure 2. Crack growth accuracy in the order of 0.1 to 0.2 mm can be achieved using this method. Automatic measurements can be performed by taking pictures at certain time intervals. A full crack growth record was obtained by video recording. Results of crack length measurements consist of data pairs (ai,Ni), i.e. the crack length ai and the corresponding number of cycles Ni. A plot of ai as a function of Ni gives the crack growth curve.



Fig. Error! No text of specified style in document.**. Experimental fatigue test setup with a camera based crack growth monitoring**

III. DISCUSSION

Figure 2 and 3 shows the improvement in the fatigue life of Al 2024-T3 repaired with metallic and composite patches at a stress ratio of 0 and 0.1 respectively. The patch materials influence directly the variation of the fatigue crack growth rate. Composite patches offers many advantages compared to the metallic patches. the main advantages of the composite materials is their high stiffness which allow the use of these materials as thin patches with minimal weights and with a minimal effect on the aerodynamic.

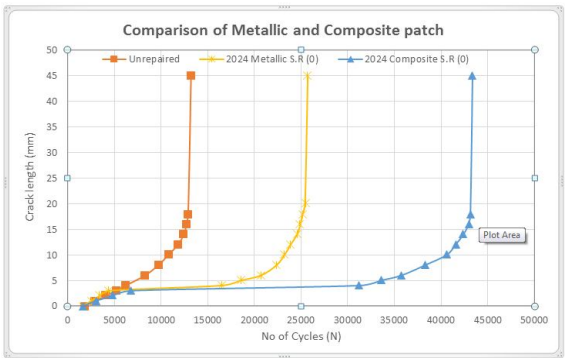


Fig. 4. Fatigue life of 2024-T3 (R=0) repaired with metallic and composite patch

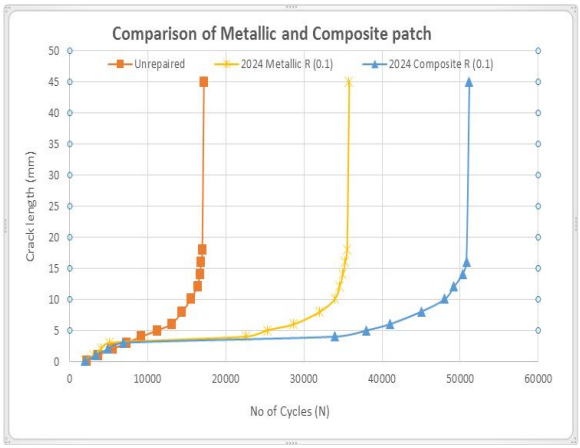


Fig. 5. Fatigue life of 2024-T3 (R=0.1) repaired with metallic and composite patch

Figure 4 and 5 shows the fatigue life (crack length vs number of cycles) for un-repaired and repaired plates with composite patch. From this, we can note that the fatigue life is highly improved by the presence of the composite patch. Indeed, the number of cycles to failure is increased by 95 % times with the presence of the metallic patch and 230 % with composite patch for zero stress ratio. While for 0/1 stress ratio the increase was 110 and 198 % for metallic and composite patch respectively. This means that the composite repair can highly improve the overall fatigue life of aircraft structures.

IV. NUMERICAL ANALYSIS

We used a two-dimensional finite element code named FRANC2D/L (FRacture Analysis Code for 2-D Layered structure) in the numerical modelling 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 mechanics [14]. In this study simplifying assumptions are made which still allow us to capture the essential features of the response. These assumptions include:

- Each layer is considered as an individual two-dimensional structure under a state of plane stress.
- Individual layers can be connected with adhesive bonds.
- It is assumed that the adhesive layer is homogeneous, linear elastic and isotropic.
- The adhesive is assumed to deform only in shear and this deformation is uniform throughout the adhesive thickness.
- The surface shear transmitted through the adhesive is assumed to act as surface traction on the adherents.

The shear stress in the adhesive is given by:

$$\tau = \frac{G_a}{e_a}(u_1 - u_2)$$

Where u1 and u2 are the displacements in layer 1 (plate) and layer 2 (patch) respectively, G_a and e_a are

the shear modulus and the thickness of the adhesive, respectively.

The whole structure (plate and patch) was meshed using the standard eight nodded plane elements with quadratic shape functions. These elements perform well for elastic analysis and have the advantage that the stress singularity at the crack tip can be incorporated in the solution [15]. Figure 5 shows a typical meshing of the plate.

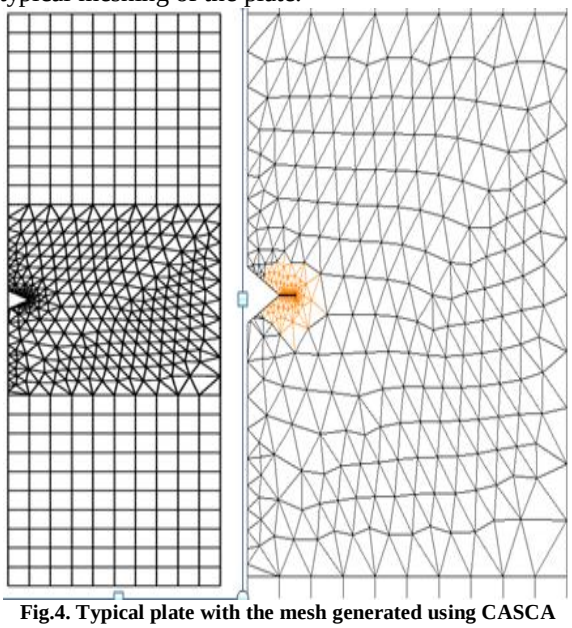


Fig.4. Typical plate with the mesh generated using CASCA

4.1 Effect of patch on stress contours

Figure 5 shows stress contours of repaired and unrepaired specimens against different crack lengths for one-sided repaired plates, where a is the plate crack length. It can be observed that there is huge reduction in the stresses near the crack tip after the reinforcement of patch. The stress near the crack tip of baseline specimen was found to be 2214.54 ksi, which was reduced to 129.36 ksi after the reinforcement of the patch. This clearly explains the beneficial effects of bonded repair technology.

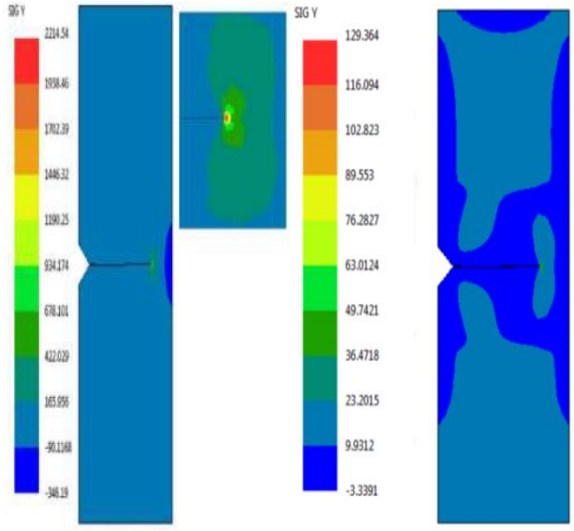


Fig..5 Stress contour of repaired and unrepaired plate

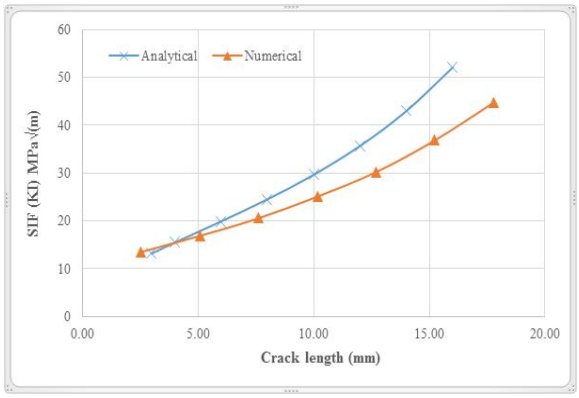


Fig.6. Comparison of the SIF unpatched specimen (12 kN) at R=0

4.2Comparison between repaired and unrepaired configuration

Figure 5 shows the variation of the stress intensity factor KI versus the crack length for patched and unpatched cracked specimen. From the figure it is clear that the stress intensity factor decreases for the patch configuration as compared to the unpatched specimen. This decrease in SIF is due to the fact that the patch carries the loads that gets bridged through the adhesive in mode I and the difference varies from 47 % to 88% using metallic and patches. Therefore, the SIF reduction difference between the two different patches is about 20% [16, 17]. This is due to the inadequate orientation of the composite patch fibres with regard to the crack growth

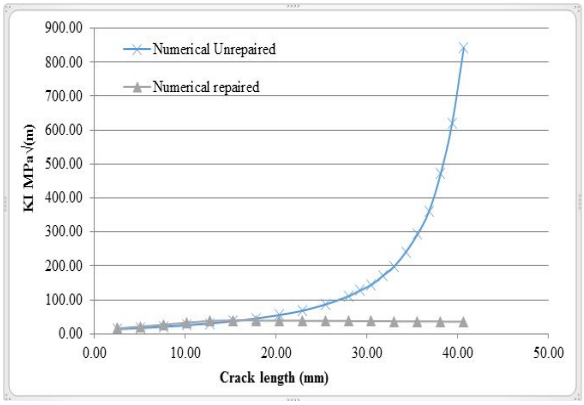


Fig. 7. Comparison of the SIF between patched and unpatched specimen (12 kN) at R=0

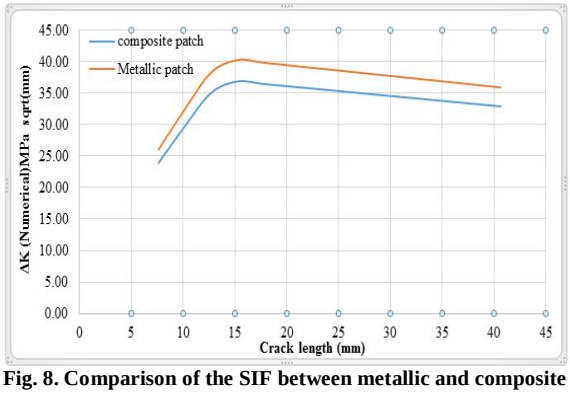


Fig. 8. Comparison of the SIF between metallic and composite patch (12 kN) at R=0

RESULT AND CONCLUSION

In this paper, fatigue crack growth behavior of edged cracked aluminum panels repaired with single side metallic and composite patches were investigated. Following are the main conclusion drawn from the experimental and numerical work.

- Fatigue life of the specimen is affected by the stress ratio in both cases i.e. patched and unpatched case.
- With the increase in the load ratio, the fatigue life increases for both repaired and un-repaired specimen because of the difference between the maximal and the minimal applied stresses ($\Delta\sigma = \sigma max - \sigma min$). The higher the difference between the maximum and the minimum stresses, the lower the fatigue life.
- The choice of the adhesive properties for the repaired cracks with a bonded patch must be optimized.
- The fatigue life with composite patch is greater than the of aluminum patch.
- Stress intensity factor is highly reduced by the reinforcement of the patch as compared to the unpatched configuration.
- The presence of a patch reduces considerably the stress concentration which can delay of the crack initiation and thereafter the increase in the life duration of the structure.

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