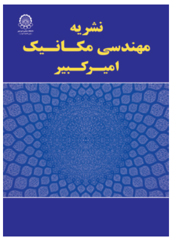

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Comparison Between Composite Patches and Bolt Clamping Force to Repair an Edge Crack in Aluminum Alloy 2024-T3 Specimens

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ABSTRACT: Many of components in various industries are working under multiaxial stresses, and since the cracks can be the source of the failure, therefore, the strength analysis of the cracked structures under mixed- mode loads and trying to increase the strength and stability of them is very important. In this paper, the effect of the composite patch and clamping force resulted from torque tightening a nut and bolt on the fracture strength of an aluminum alloy 2024-T3 plate having an edge crack has been compared experimentally and numerically. The cracked test specimens were loaded using modified Arcan fixture to create pure opening fracture mode (mode I), pure in-plane shear fracture mode (mode II) and mixed mode of (I and II). In the numerical part, Ansys finite element package was used to simulate the test specimens performance. The results of this study showed a significant increase in tensile strength of the repaired components by using these two methods compared to simply cracked specimens. Thus, an increase of 44% in the tensile strength of mode I can be achieved with a composite patch, however, the strength increase is reduced to 18% in pure shear mode. Clamping force also increases the fracture strength in mixed mode. This increase is 24% for pure shear mode and it reaches 9% in the pure tensile mode.

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1- Introduction

It is very important to prevent crack development and propagation to maintain engineering structures and the equipment safe alongside with crack detection. Crack repair is performed via either retarding propagation or preventing crack growth, which can be performed by reducing stress intensity factors at the crack tip via imposing compressive residual stress [1, 2] or decreasing stress concentration at the crack tip [3, 4]. Among other repair methods, repairing by bolt clamping force [1, 2] and composite patches [5, 6] has been widely studied and recognized as important methods in this regard. However, either method comes with its own advantages and disadvantages. In the present paper, the effect of repair using the composite patch and clamping force from bolt pre-tension on fracture strength and stress intensity factors in pure opening mode, pure in-plane shear mode, and mixed modes of loading are evaluated and compared using Arcan test fixture, both experimentally and theoretically.

2- Experimental Tests

In the practical approach, modified Arcan fixture [7] was used to undertake fracture tests in different modes (Fig. 1). Tensile tests at each loading ratio were undertaken in three series: 1) with no repair or simple edge cracks, 2) repaired with composite patches, and 3) repaired with bolt clamping. Accordingly, maximum applied load to the fracture (residual strength) was obtained for the samples. Fig. 2 presents the results of the experimental tests on the three series of samples. Comparing the results, it is evident that when loading is 100% in mode I, the composite patch by far outperforms the bolt clamping in enhancing repaired samples' strength.

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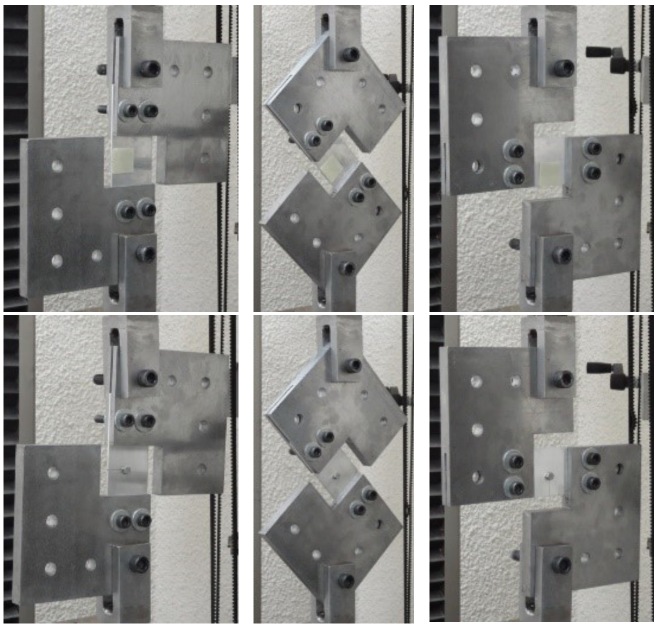


(a) (b) (c)

Fig. 1. Patched and bolted specimens on the modified Arcan fixture a) 100% Mode I, b) 50% Mode I c) 0% Mode I

However, when loading is 100% in mode II, the bolt clamping has outperformed the composite patch when it comes to enhancing the repaired sample's strength.

3- Numerical Method

In order to investigate theoretically the effect of the composite patch and bolt clamping or bolt pre-tension on the stress

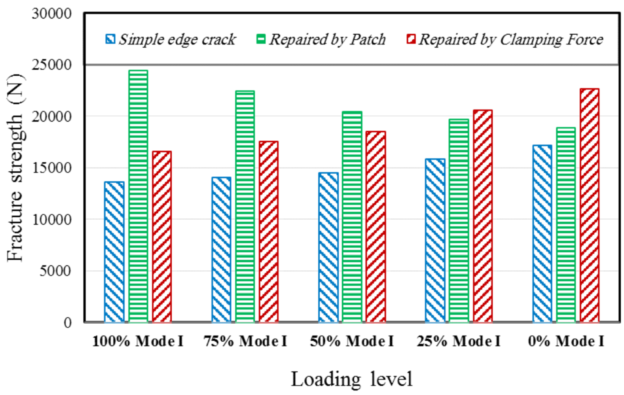
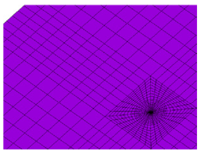


Fig. 2. Fracture force (strength) of simple edge crack and repaired specimens.

intensity factors, Finite Element Method (FEM) was used by employing ANSYS software (Fig. 3). Modified Arcan fixture along with the samples was three-dimensionally modeled as integrated objects. Mechanical properties of the materials, which are needed for Finite Element (FE) model, were all determined through standard tests.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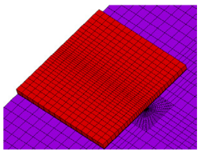
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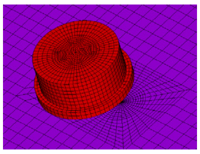
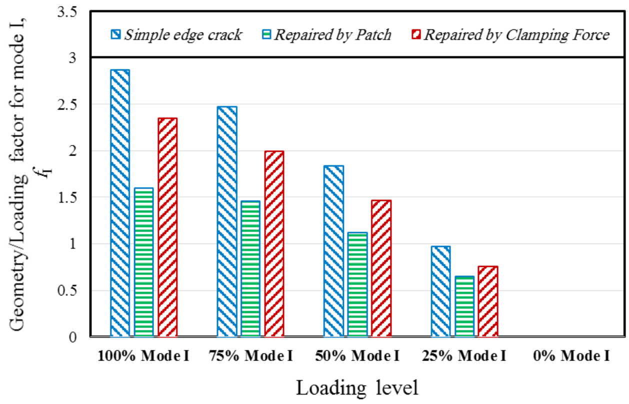

(c)

Fig. 3. Meshes of a) simple edge crack b) patched specimens c) bolted specimens

4- Results and Discussion

Fig.4 (a) demonstrates the bar plot of the values of geometry/loading factor in mode I for the samples repaired with a bolt and composite patch under five different mixed loading scenarios. The value of geometry/loading factor in pure mode I decreased by 44% and 18% for the composite patch and clamping force, respectively. However, as the contribution of mode, I loading is reduced, the effectiveness of the composite patch on decreasing the geometry/loading factor is reduced while that of the bolt clamping force is boosted. Fig.4 (b) compares the values of geometry/loading factor in mode II for the two repairing methods, namely composite patch, and bolt clamping force. In the case where loading is 100% in mode II, the value of geometry/loading factor in mode II for the repairing procedure based on clamping force resulted from bolt pre-tension and composite patch exhibited 24% and 9% reduction, respectively. The results obtained from the numerical analyses on the effective stress intensity factor are demonstrated in Fig.4 (c). As can be seen in the figure, when loading is 100% performed in mode I, effective geometry/loading factor (feff) decreases by 44% in the sample repaired with the composite patch. However, when the contribution from mode I is decreased, the above parameter drops accordingly, so that it becomes 9% when loading is 100% performed in mode II. It is further observed that when loading is 100% performed in mode I, effective stress intensity factor reduced for the sample repaired with bolt clamping force by 18 %; this percentage increases by decreasing the contribution of mode I, so that it approaches 24 % when loading is 100 %



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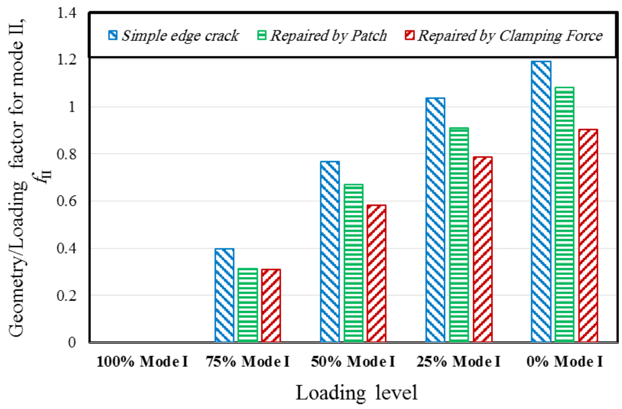

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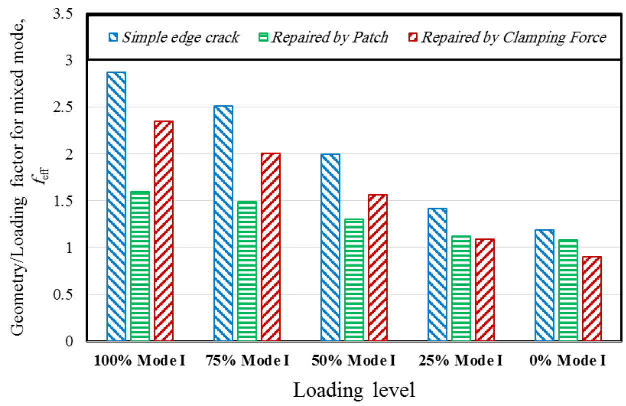

(c)

Fig. 4. The geometry/loading factors for different loading levels of simple edge crack and repaired specimens at the fracture load for, a) mode I b) mode II c) mixed mode.

performed in mode II.

5- Conclusions

- Experimental results indicate that the required force to make the repaired samples fail in pure mode I, pure mode II and mixed modes is larger than those of simply cracked samples. However, this enhancement is more sensible in pure tensile mode, rather than pure shear mode.
- For loading in pure mode I, composite patch represents the most appropriate repairing method as it imposes

the largest contribution to the enhanced strength of the repaired sample.

- For loading in pure mode II, repairing by clamping force resulted from bolted pre-load represented the most effective repairing method as it increased sample strength further.

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