EXPERIMENTAL FAILURE ANALYSIS OF WET-PATCH-REPAIRED U NOTCHED COMPOSITE PLATES

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In this study, it was achieved failure analysis of wet-patch-repaired composite plates, experimentally. U notched composite plates were repaired with wet patch and then static tensile load was applied to composite plates. The patch thickness, single and double patch repair and fiber orientation angle of composite plates effect on the failure load were investigated. The composite plates having eight plies woven glass fiber and epoxy matrix resin, woven glass fiber and epoxy based adhesive were used as materials. The wet patches were obtained by epoxy adhesive impregnated to the woven glass fibers. As a result of experimental study, it was determined that the failure load was increased with increasing patch thickness. Also, it was seen that the double patch was more effective repair technique than single patch and the fiber orientation angle increasing was decreased the failure load of the composite plates.

Keywords— Composite plates, repair with adhesive and patch, failure analysis.

1. Introduction

The composite materials have improved mechanical properties. However, this material was not instable in view of impact and the mechanical properties and failure behavior of this materials were complex than the isotropic materials. Especially, thermoset based composite plates were brittle structure and it was not showed yield behavior. Such materials were suddenly failure and these were not showed too much displacement. The composite materials were too expensive than the traditional materials and repairing process of this materials were too hard. Because of the cost of materials, repair was too cheap than changing new one [1]. In the repairing process of failure composite materials, the mechanical connections or adhesive connections were used. The mechanical connection could cause stress concentration near the hole of junction piece and thus, adhesive connections were preferred than the mechanical connections [2]. The failure plate was repaired at the outer surface with adhesive and patch. Major aim of repairing process reduced the stress concentrations where was appeared near the notch and geometric discontinuities [3]. When a failure plate was repair with adhesive and patch, the external patch and wet patch could be used as patch. The wet patch was applied by placing adhesive impregnated fiber layer. The adhesive impregnated fiber layers were put on the repair place (failure zone). This repair type can be easily applied without disrupting the geometric structure of the component surface and thus, it can be carried out without detriment to the external appearance and aerodynamic structure of vehicle [4]. The major failure type which were appeared in repairing process with adhesive and patch, were presented in figure 1. In the first type of failure, the composite was failure and any failure could not appear in the repaired zone. In the second type of failure, the composite plate and patch were failure together. In the third type of failure, the failure was appeared in adhesive which were between composite plate and patch and then, the patch was peel from the composite plates and the composite plates were fractured from the notch.

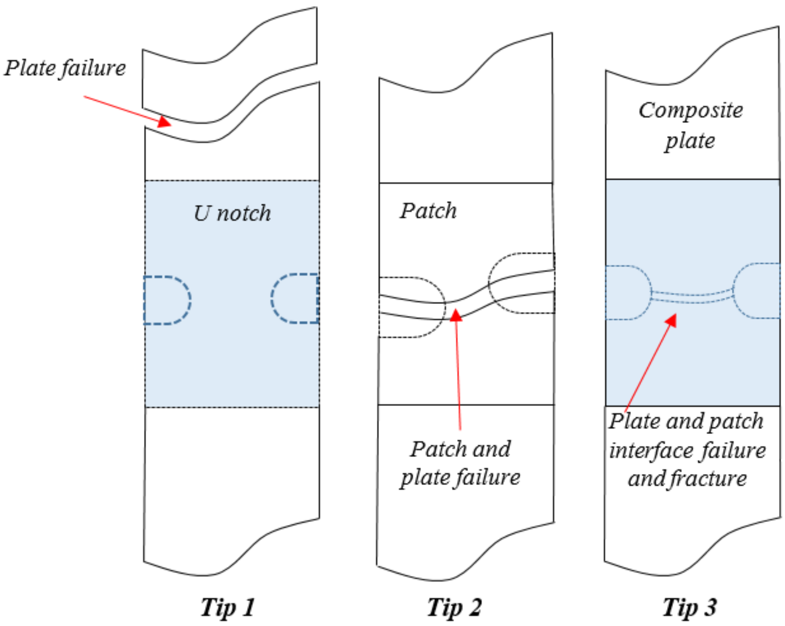

Figure 1. The major failure types which were appeared in repair with adhesive and external patch.

The various research was made in the literature for repairing composite patch and adhesive. Liu and Guoping [1], Turan and Kaman [4] were investigated the adhesively patch repaired composite plates which were central circular notch. Campilho etal [2]. were researched single and double lap repair of composite plates. Madani etal [3]. were researched stress intensity factor in notched aluminum plate which was repaired with adhesive and external-patch. Papanikosetal. [5] were investigated the failure behaviors of adhesively external-patch repaired edge-notched composite plates. Her and Chao [6] were studied variations of stress intensity factor experimentally and analytically in adhesively external-composite patch repaired plates. Bouiadjra etal. [7] were investigated variations of stress intensity factor in adhesively patch repaired composite plates with changing of single and double patch, patch thickness and the shear modulus of adhesive. Achour etal. [8] were researched stress intensity factor in adhesively patch repaired semi-circular edge notched composite plates. Ouad etal. [9] were realized stress analysis in adhesively patch repaired cracked aluminum plates which were used in air vehicles with experimentally and numerically. Atas et al. [10] were analyzed the impact failure of adhesively patch repaired and un repaired composite plates. Çelik and Turan [11] were investigated failure behaviors of notched composite plates.

In this study, the failure analysis of U notched composite plates, which were repaired with using wet patch, were investigated experimental studies. The failure loads were determined with static tensile test. The fiber orientation angle of composite plates was used as 0^o, 15^o, $30^o$and $45^o$and the fiber orientation angle of patch was used as 0^o. The patch thickness effect on the failure loads were investigated for using 2, 3 and 4 layers. The U notched plates were repaired single and double sided and the failure loads of repaired composite plates were compared with un-notched and notched (un-repaired) composite plates. The obtained results were presented as tables and graphs.

2. Experimental study

In the experimental study, the composite plates were used as dimension of 30x150x1.25 mm. The U notch, which were opened in the edge of composite plates were repaired single and double side with wet patch. The geometry and notch dimensions of the problem were presented in figure 2.

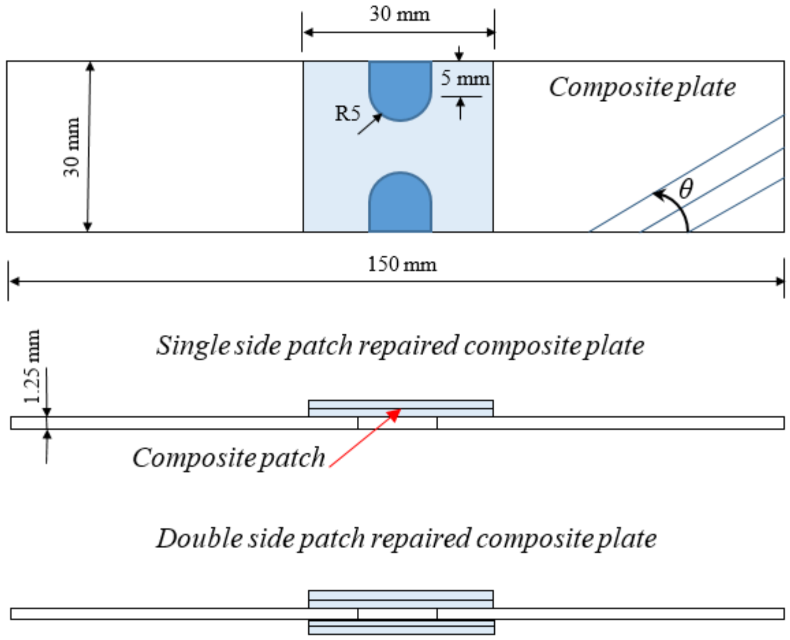

Figure 2. Definitions of Problem.

The eight layered woven fiber glass reinforced epoxy matrix resin composite plates were used as composite plates with using $[\theta]_8$ layer arrangement angle. The layer arrangement angle θ was used as 0°, 15°, 30° and 45°. The layer arrangement angle of patch was used as 0°. In the repair process, the failure plates were repaired with single sided and double sided. In the investigation of patch layer number effect on the failure load, the layer number was selected as 2, 3 and 4 layer. The composite plates were bought in Izoreel firm. The composite plate's width, length and thickness were constant and they were 30 mm, 150 mm and 1.25 mm, respectively. The U notch was opened in the plate with using milling cutter. The notched area was sanded with 40 grid sand paper and then the repairing surfaces were cleaned with cotton cloth and acetone.

The woven glass fiber and epoxy based adhesive were used as patch materials. The density of glass fiber was 270 gr/m^2. The epoxy based adhesive was composed of two components and it was used as commercially. The glass fiber was lay on the clean surface and the adhesive was impregnated to fiber. Then, the fiber layer was cut as 30mmx30mm dimensions. The adhesive impregnated layers were lay on the repaired surface with hand. The outer surface wet patch was covered with acetate and the repaired specimens were waited in the room conditions during 1 week for curing. At the end of curing time, the specimens were testing under static tensile load. In the static tensile testing, the specimens were squeezed the jaws of Instron BS8801 tensile testing machine and the tensile loads were applied with 1 mm/min tensile speed. The tests were continued when the specimens were cracked. At the end of the tests, the load and displacement values were recorded in the computer and the load-displacement graphs were generated. The load-displacement results of single-patch and double patch repaired composite plates were presented in figure 3 and figure 4, respectively. Also, the patch layer number effects on the failure load were presented these graphs.

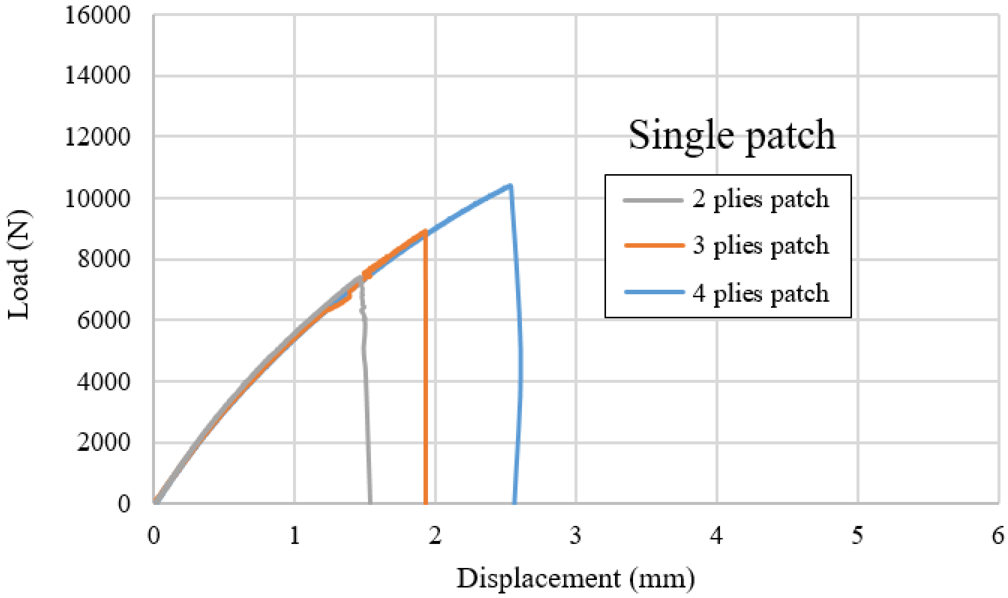

Figure 3. The load-displacement graphs for single patch repaired composite plates with increasing of patch layer number.

As seen in the figure 3, the increase in the number of patch layers (plies) was increased the failure loads and displacement. Also, approximately linear increase in load values can be seen in figure 3. The minimum failure load was obtained for 2 layer (plies) of patch as 7428 N and the maximum failure load was obtained for 4 layers of patch as 10418 N.

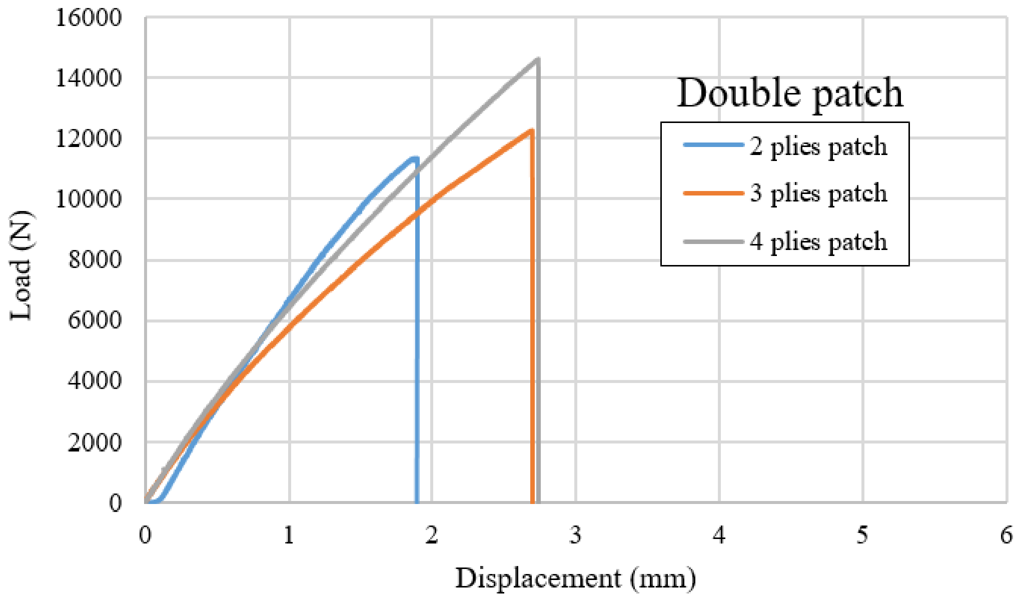

Figure 4. The load-displacement graphs for double patch repaired composite plates with increasing of patch layer number.

As seen in the figure 4, the failure loads were increased with increasing number of layers of patch. The minimum failure load was obtained for 2 number of patch as 11362 N and the maximum failure load was obtained for 4 number of patch as 16432 N. The failure load variations for single patch repaired composite plates were presented in figure 5 with increasing of fiber reinforced angle of composite plates.

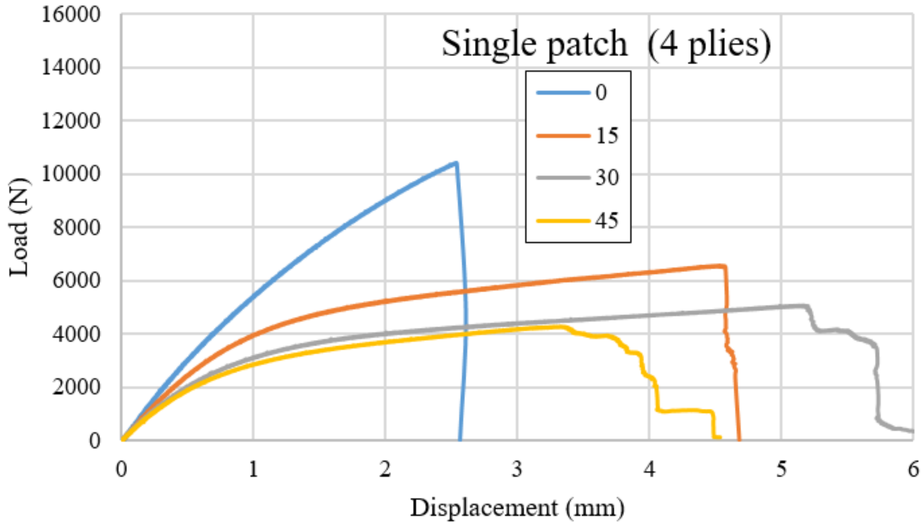

Figure 5. The load-displacement graphs for single patch repaired composite plates with increasing of fiber reinforced angle of composite plates.

As seen in figure 5, increasing of the fiber reinforced angle of composite plates was decreased the failure loads. The maximum failure load was obtained for 0° fiber reinforced angle values as 10418 N and the minimum failure load was obtained for 45° fiber reinforced angle as 3624 N. When the fiber reinforced angle values was increased, the failure loads of composite plates were decreased [11].

3. Results and Discussions

At the end of the experiments, the results were presented as changing of number of patch layers and fiber reinforced angle effect on the failure load both single and double patch repair situation. The failure loads variations of single and double patch repaired composite plates were compared un-notched and un-repaired composite plates and these results were presented in figure 6.

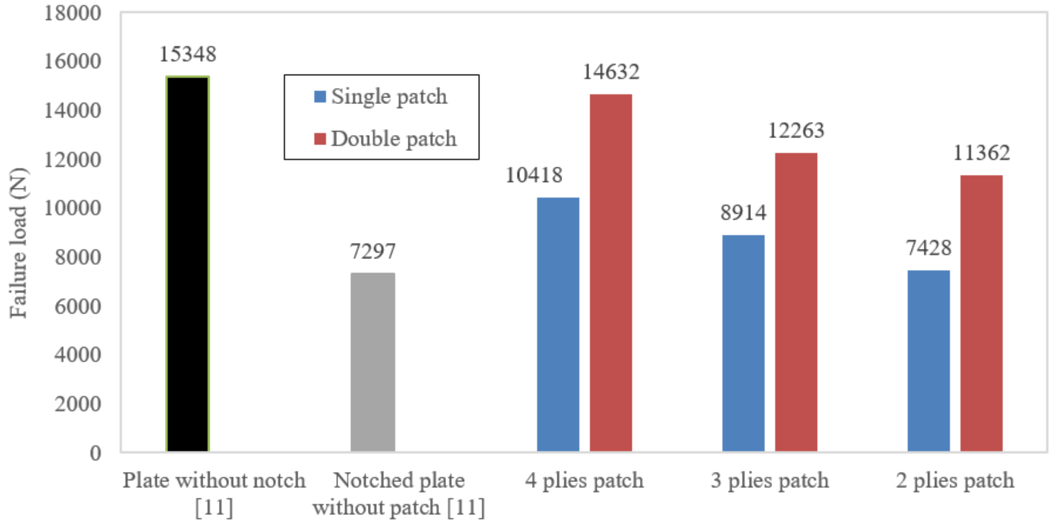

Figure 6. The effects of the number of patch layers on failure loads on single and double patch repaired composite plates.

The patch layer number effect on the failure loads were investigated for 0° fiber reinforcement angle. The U notched composite plates were repaired with 2, 3 and 4 patch layer. It can be seen that the patch layer number increasing was increased of failure load in figure 6. The minimum failure load was obtained for two layer and single patch repaired composite plates as 7428 N and the maximum failure load were obtained for four layer and double patch repaired composite plates as 14632 N. When the failure load of un-repaired (notched) composite plates was compared to single and double patch repaired composite plates, it can be seen that, the failure load was increased between 2% to 100% ratios. The figure 7 was showed that the failure types of adhesively patch repaired composite plates.

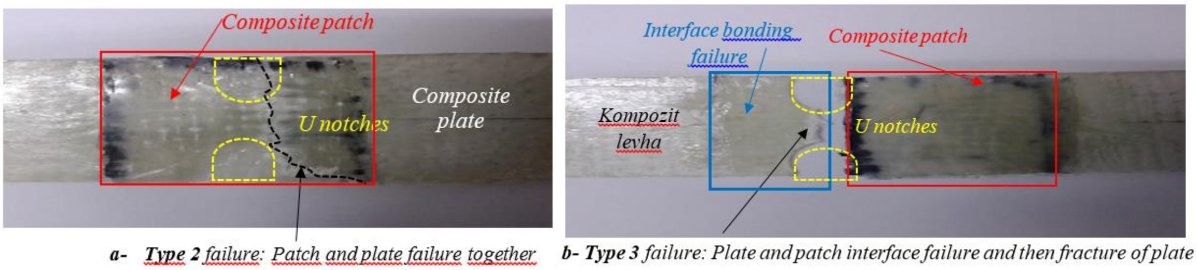

Figure 7. Failure types evaluation of double patch repaired composite plates. **a-** Failure type 2, **b-** failure type 3.

The figure 7-a was presented the results of double-patch repaired and two layers of patch. Also, the figure 7-b was presented the results of double-patch and four layers of patch. As a results of experiments the type 2 failure were seen when the layer number were two layers. When, the layer number was four, the failure type was seen as type 3. As a result of the application of four layers of patch, it was observed that the composite plate was separated from the interface with the patch, and then the plate was failure by the notch zone (type 3). This situation was showed that the two layers of patch were extended with the composite plates well and it was failure with the composite plates. The four layers of patch were stronger than the composite plates and it was not extended with composite plates. As a result of using of four layers of patch, the repaired composite plates were failure as type 3.

The fiber reinforced angle effects on the failure load were investigated in single-patch repaired composite plates and the four layer of patch were used in the repair process. The fiber reinforced angle variations were used as 0°, 15°, 30° and 45°. The fiber reinforced angle effects on the failure loads of single-patch repaired composite plates were presented in figure 8.

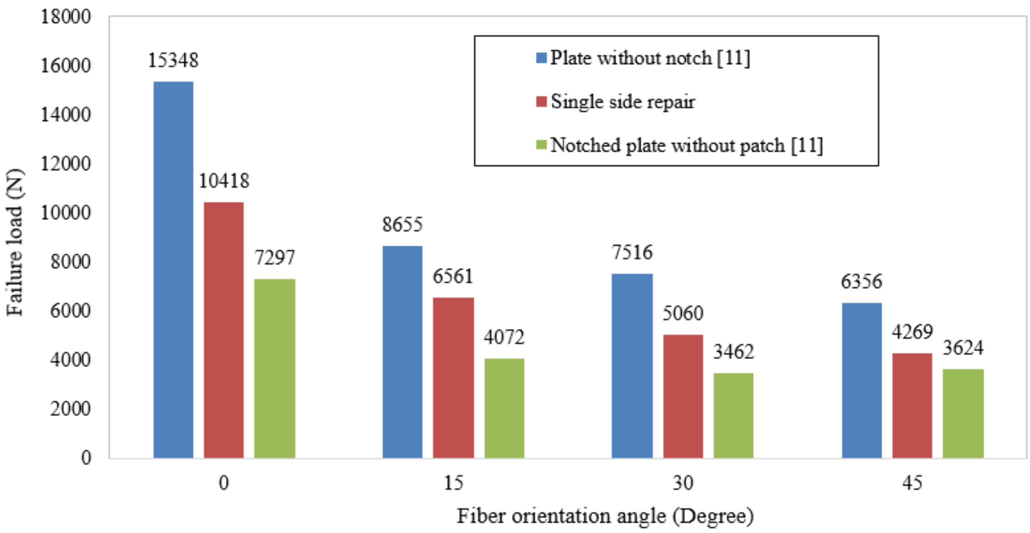

Figure 8. The fiber reinforced angle effects on the failure loads of single-patch repaired composite plates.

The failure loads were decreased with the fiber reinforced angle increasing and this situation could be seen in the figure 8. The minimum failure load was obtained for 45° fiber reinforced angle as 4269 N and the maximum failure load was obtained for 0° fiber reinforced angle as 10418 N. When the repaired composite plates were compared the un-repaired (notched) composite plates, the failure loads were increased between 18 % and 61% ratios.

4. Conclusions

In this study, failure behaviors of adhesively patch repaired U notched composite plates were investigated with statically tensile testing experiments. The single and double patch, fiber reinforced angle of composite plates and number of patch layer count were used as parameters. Obtained results were discussed as below:

- The failure load and displacement in failure load values were increased with increasing count of layer numbers for single patch repaired composite plates and double patch repaired composite plates.
- The fiber reinforced angle increasing was decreased failure load of composite plates. But, the fiber reinforced angle increasing was increased displacement values of failure plates and the maximum elastic load in the load-displacement graphs was reduced.
- The failure loads of double patch repaired composite plates were bigger than the single patch repaired composite plates. This situation was not influenced by the increasing in the number of patch layers.
- The failure loads of all repaired plates (single and double patch) were smaller than the un-notched composite plates, however it was bigger than the un-repaired (notched) composite plates. The failure load of four patch layered and double patch repaired composite plate was close to un-notched composite plates.
- The failure type of adhesively patch repaired composite plates were affected the count of patch layers. When the two layers were used as patch, the failure type was observed as type 2. However, when the four layers were used as patch, the failure type was observed as type 3.
- As a result of this study, it can be suggested that the designer must be taken into consideration the number of patch layer, the fiber reinforced angle and single and double patch repair parameters. Because, the optimum failure behaviors of adhesively patch repaired composite plates could be understood through use of these parameters.

5. References

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