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RESEARCH ARTICLE

The Effect of Patching Properties on Tensile Stress Behaviors in the Repair of Composite Plates

Mehmet Ramazanoğlu, *1 Abdullah Şişman

Grand Metal San. ve Tic. A.Ş., Kahramanmaraş, Turkiye
mehmetramazanoglu46@gmail.com, orcid.0000-0001-6860-0895
*1Kahramanmaraş Sütçü İmam University, Faculty of Engineering and Architecture, Kahramanmaraş, Turkiye
asisman@ksu.edu.tr, orcid.0000-0001-9898-2556

HIGHLIGHTS

- *Effect and importance of patch properties in the repair of composite plates*
- *Damaged materials should be repaired with larger patches with the same or more layer number*
- *Damage repair with adhesive joints brought the strength of the damaged area back to state before the damage*
- *Damage repair with adhesive joints is quite successful*

Keywords:

- Glass Fiber Reinforced Composite
- Single-Sided Lap Joints
- Tensile Stress Properties

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***Correspondence:**
Abdullah Şişman
asisman@ksu.edu.tr
Gsm: +90 535 7304040

GRAPHICAL ABSTRACT

In this study, the effect of patch sizes and number of patch layers on tensile stress behavior in the repair of elliptical damaged laminated composite sheets was investigated experimentally. For this purpose, glass fiber reinforced laminated composite sheets with elliptical holes were prepared. These plates were subjected to tensile loads and their failure loads were determined experimentally. Then, using DP460 adhesive material, glass fiber reinforced composite sheets with elliptical damage were repaired using single-sided lap joints with glass fiber reinforced composite patches of varying sizes and layer numbers, and the repaired samples were subjected to tensile loads and their failure loads were determined and its effects on stress behavior were also investigated experimentally.

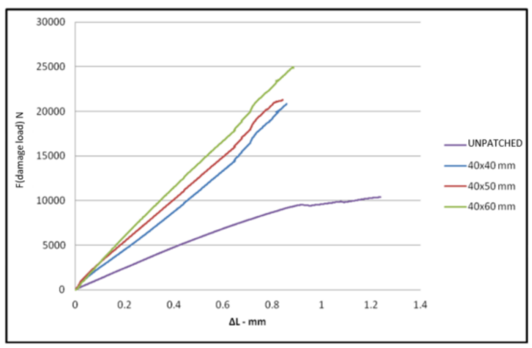

Figure A. Failure load changes for patches of 40x40 mm, 40x50 mm, 40x60 mm with 4 layers.

Aim of Article : *In this study, it was aimed to determine the effect of patch properties on tensile stress behaviors in the Repair of composite plates.*

Theory and Methodology : *Patches with different properties were adhered to the composite material with a one-sided lap joint using DP460 adhesive. The tensile tensile strengths of the repaired specimens were investigated experimentally.*

Findings and Results: *Damaged materials should be repaired with larger patches with the same or more layer number.*

Conclusion : *Damage repair with adhesive joints brought the strength of the damaged area back to state before the damage. Damage repair with adhesive joints is quite successful*

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ABSTRACT

In this study, the effect of patch sizes and number of patch layers on tensile stress behavior in the repair of elliptical damaged laminated composite sheets was investigated experimentally. For this purpose, glass fiber reinforced laminated composite sheets with elliptical holes were prepared. These plates were subjected to tensile loads and their failure loads were determined experimentally. Then, using DP460 adhesive material, glass fiber reinforced composite sheets with elliptical damage were repaired using single-sided lap joints with glass fiber reinforced composite patches of varying sizes and layer numbers, and the repaired samples were subjected to tensile loads and their failure loads were determined and its effects on stress behavior were also investigated experimentally.

Keywords: *Glass Fiber Reinforced Composite, Single-Sided Lap Joints, Tensile Stress Properties*

I. INTRODUCTION

Composite materials and especially fiber-reinforced composite materials are used primarily in aircraft structures, automotive, etc., due to their high strength/weight ratio. It is increasingly used in all fields and sectors. In structures where composites are used, various damages can be seen due to many reasons such as various impacts, fatigue life, mechanical and dynamic vibrations and temperature changes. Replacing a damaged structure is extremely costly and sometimes impossible. Especially in the aviation industry, there are structures with very high costs. As mentioned above, these structures are repaired in order to eliminate the discontinuities that may occur due to various reasons. Mechanical and adhesive repair techniques are generally used for the repair of these damages. Adhesive joints are increasingly preferred due to their uniform stress distribution, lightness, high fatigue strength and development of increasingly stronger adhesives.

In recent years, many studies have been carried out on this subject. For example, Ergün [1] studied the tensile properties of repairing elliptically damaged aluminum plates with composite patch experimentally and numerically. Gülakman [2] worked on the production of glass fiber / epoxy material, determination of its mechanical properties and calculation of interface fracture toughness. Three point bending test, double fixed beam test technique, single notch edge tensile test and compact tensile test were performed with experimental analysis. Li et al. [3] used the composite patching technique to repair helicopter tail shafts damaged in wars. As a result, they found that the composite patches completely repaired these structures. In addition, experimental and numerical methods showed closeness to each other. Rachid et al. [4] investigated the effect of patch shape on efficiency and durability in aircraft structures repaired with bonded composite and developed a three-dimensional finite element method. According to Ramji et al. [5], they developed a three-dimensional finite element method to find the optimum composite patch shape. They determined the patch shapes as circle, square, ellipse, rectangle, rectangular octagon and elongated octagon. As a result, the best performance was observed in materials with elongated octagonal patches. Özgür [6] studied the bonding parameters of the rubber material pair by using the post-gluing method. According to Soy [7] they studied the adhesive repair of Al 2024-T3 alloy plate with composite patch with the help of computer aided modeling. Tensile and bending stress behaviors were investigated by experimental and numerical analysis. Tek [8] studied stress analysis in single and double lap adhesive joints. Comparisons were made in damage loads with experimental and numerical analyzes. Gültekin et al. [9] studied experimental and numerical determination of the tensile properties of different single-lap joint types with adhesives in different thicknesses. They found that the change in the adhesive thickness and the adhered material thickness affect the experimental damage loads. Demir et al. [10] worked on the effect of support patches in single-lap joints with adhesives on damage loads. They found that support patches increased the failure loads effectively. Adin et al. [11] studied on the effect of patching aluminum with composite patches on the fatigue stresses numerically. They found that patching with composites increased fatigue life significantly. Adin et al. [12] worked on the effect of patching aluminum pipes on the fatigue stresses numerically. They saw that patch dimensions are important in fatigue stresses and higher fatigue stresses were obtained in quarter-circle patches. Adin et al. [13] examined the double-reinforced adhesive joints strength and they stated the reasons of widespread uses of aluminum alloys and glass fiber reinforced composite materials. Akpınar [14], worked on tensile failure loads of different lap joint types. After experiments, he observed a significant increase in failure loads in the three-step lap joints. Durmuş et al. [15] analyzed three step-lap joints adhesively bonded with different step lengths. As the first step length increases They have seen increased damage loads. Temiz et al. [16], studied the increase in strength of single lap joint by residual stresses caused by bonded curvature. They noted that the reason of the pressure perpendicular to the overlap area was the trend of the elastic material to go back to its starting shape after curing.

II. MATERIALS AND METHODS

In this study, glass fiber reinforced composite material was used as patch and bonded material to form a single-sided lap joint. These composite materials were obtained from İZOREEL company in İzmir. The cutting process was made according to the size of the glued and patch material to be used. Materials bonded with 4-layer glass epoxy were cut in 140x60x1 mm dimensions, with elliptical holes. The mechanical properties of the glass fiber reinforced composite material are given in Table 1.

Table 1.
The mechanical properties of the glass fiber reinforced composite material

Cam Elyaf Takviyeli Kompozit Malzeme	
E_x	44 (GPa)
E_y	20 (GPa)
E_z	20 (GPa)
G_{xy}	4 (GPa)
G_{xz}	4 (GPa)
G_{yz}	3 (GPa)
υ_{xy}	0,32
υ_{xz}	0,32
υ_{yz}	0,41

E : Modulus of Elasticity
G : Shear Module
υ: Poisson Ratio

The patches are made of glass epoxy composite sheets with 2, 4 and 6 layers (0.5 mm, 1 mm, 1.5 mm thickness), cut in sizes 40x40 mm, 40x50 mm, 40x60 mm, 50x40 mm and 60x40 mm In this study, DP-460 was used as the adhesive material having epoxy and accelerator components by high strength volume ratio of 2/1. Special spiral tips are used to provide this ratio. The mechanical properties of the adhesive material are given in Table 2, and the shape and dimensions of the damaged samples and patches are given in Figure 1, Figure 2,

Figure 3 and Table 3.

Patched lap joints obtained using DP460 adhesive material are shown schematically in Figure 3. 0.15 mm, which is the ideal adhesive thickness for DP 460 adhesive, was chosen for bonding composites and this thickness was fixed with measurements during applications.

Table 2.
Mechanical properties of adhesive material (DP-460)

Modulus of Elasticity	2077.1 MPa
Poisson Ratio	0.38
Tensile Strength	44.616 MPa

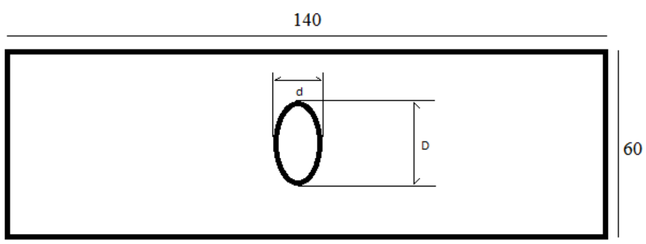

Figure 1. Glass fiber reinforced composite bonded material with elliptical holes.

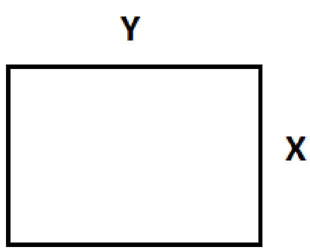

Figure 2. Glass fiber reinforced composite patch.

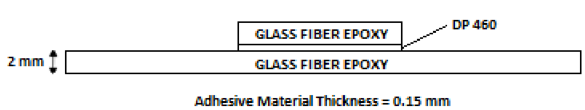

Figure 3. Schematic representation of the prepared test samples.

Table 3.
Sample parameters and values

EXPERIMENT SAMPLE DIMENSIONS						
DAMAGED PLATES (4 Layers, 0-90 Fiber Angle, Glass-Epoxy Composite)				PATCHES (0-90 Fiber Angle, Glass-Epoxy Composite)		
Sheet Size (mm)	Adhesive Thickness (mm)	Elliptical Damage Size		patch Material Size		patch thickness
		D Large Ellipse Diameter (mm)	D Small Ellipse Diameter (mm)	X (mm)	Y (mm)	Z (mm)
60x140x1	0.15	24	11	40	40	0.5mm (2 layers)
				40	50	
				40	60	
				50	40	
				60	40	
				40	40	1mm (4 layers)
				40	50	
				40	60	
				50	40	
				60	40	
				40	40	1.5mm (6 layers)
				40	50	
				40	60	
				50	40	
				60	40	

Photographs of some of the test specimens prepared using DP460 adhesive material are shown in Figure 4.

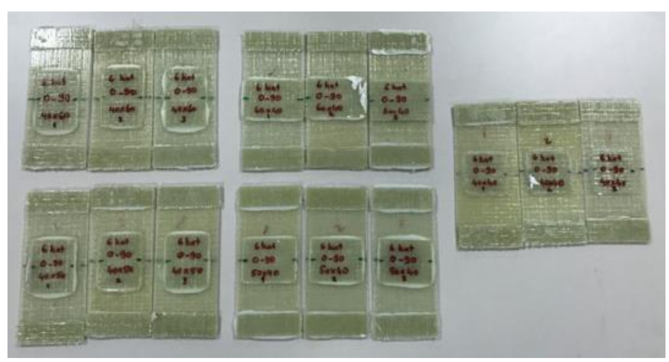

Figure 4. Photographs of some of the prepared test samples.

III. DETERMINATION OF EXPERIMENTAL FAILURE LOADS

All experiments were carried out with ZWICK Z100 tensile testing machine, under computer control, at room temperature of 50% humidity, at a constant drawing speed of 1 mm/min which is the ideal drawing speed for anisotropic and composite materials. Tensile tests were carried out on undamaged unpatched samples first, then on unpatched samples with elliptical damage, and then on samples patched with one-sided lap joints with elliptical damage. The tests were carried out in 3 repetitions. After the experiments were completed, the samples were observed thoroughly, the damaged areas were examined and their photographs were taken. The maximum loads and damage types of the samples were recorded. The ZWICK tester is shown in Figure 5.

Figure 5. ZWICK Z100 testing machine.

The moment at which a patched sample breaks from outside the patch area of glass epoxy plate while it is between the jaws of the tensile device is given in Figure 6. Average failure loads and damage types for each orientation are given in Table 4. After the experiments were completed, the samples were thoroughly observed and the damage areas were examined.

Figure 6. Sample break time**.**

Table 4.
Failure loads and damage types of lap joints

Patch Layers	Patch Dimensions (Width x Length)	Experimental Failure Load (N)	Damage Types
Undamaged Unpatched	-	27508	-
Damaged Unpatched	-	10500	BFES
2 Layers	40 x 40	20400	BFES
	40 x 50	21800	BFES
	40 x 60	22800	BFES
	50 x 40	20633	BFES
	60 x 40	21100	BFES
4 Layers	40 x 40	21500	BOP
	40 x 50	22300	BOP
	40 x 60	24067	BOP
	50 x 40	24567	BOP
	60 x 40	24967	BOP
6 Layers	40 x 40	23093	BOP
	40 x 50	26307	BOP
	40 x 60	26921	BOP
	50 x 40	24918	BOP
	60 x 40	25764	BOP

BFES: Break from Ellipse Section
BOP: Break Out of the Patch

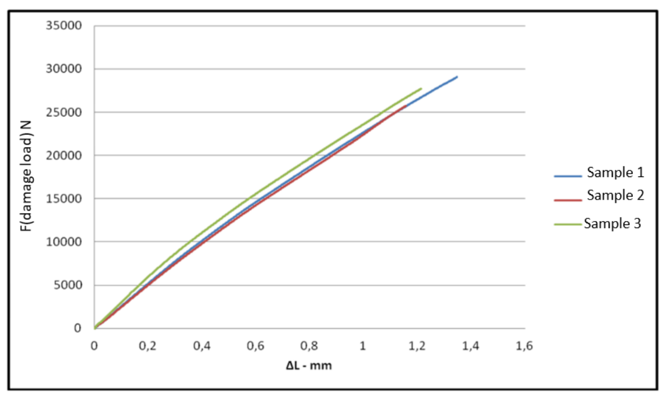

Figure 7. Failure load variation of 3 undamaged and unpatched samples.

In Figure 7, an average failure load of 27508 N is seen in the tests performed without damage and patch.

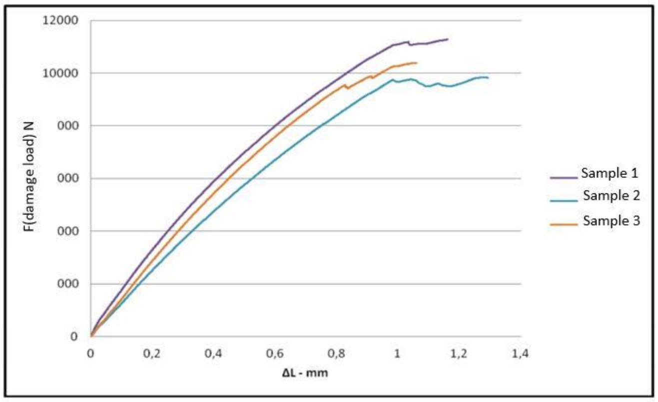

Figure 8. Failure load variation of 3 damaged and unpatched samples.

In Figure 8, an average failure load of 10500 N is seen in the tests of damaged and unpatched samples. Damaged specimens show 62% loss of strength.

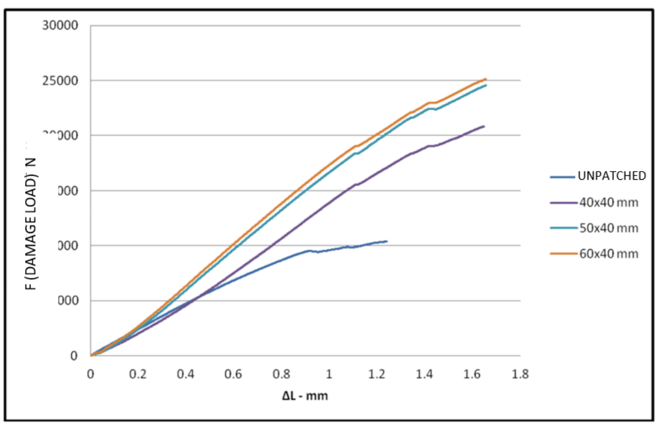

Figure 9. Failure load changes for patches of 40x40 mm, 50x40 mm, 60x40 mm with 4 layers.

In Figure 9, it is seen that as the patch length (y) and thickness (z) are kept constant and the patch width (x) increases, the failure loads increase because the adhesion surface areas also increase. Samples with 4 layers and 40x40 mm patches showed an average failure load of 21500 N, samples with 50x40 mm patches showed an average failure load of 24567 N, and samples with 60x40 mm patches showed an average failure load of 24967 N.

Compared to the elliptical damaged samples exposed to tensile load without patch, it is seen that samples with 40x40 mm patches carry 104% excess load, samples with 50x40 mm patches carry 133% more load, and samples with 60x40 mm patches carry an excessive load by 137%.

As a result, as the patch width increases, the failure loads of the samples increase as the adhesion area increases.

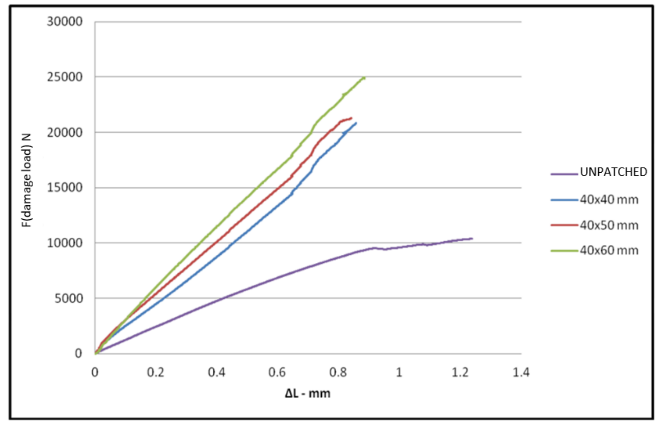

Figure 10. **F**ailure load changes for patches of 40x40 mm, 40x50 mm, 40x60 mm with 4 layers.

In Figure 10, it is seen that the failure loads increase as the adhesion surface area increases as the patch width (x) and thickness (z) are kept constant and the patch length (y) increases. The number of layers is 4, 40x40 mm samples resisted an average failure load of 21500 N, 40x50 mm samples showed an average failure load of 22300 N and 40x60 mm samples showed an average failure load of 24067 N.

According to the elliptical damaged samples exposed to tensile load without patch, it is seen that samples with 40x40 mm patches carry 94% more load, samples with 40x50 mm patches carry 112% more load, and samples with 40x60 mm patches carry an excess load by 129%.

As a result, an increase in the failure loads of the samples was observed as the adhesion area increased as the patch length increased.

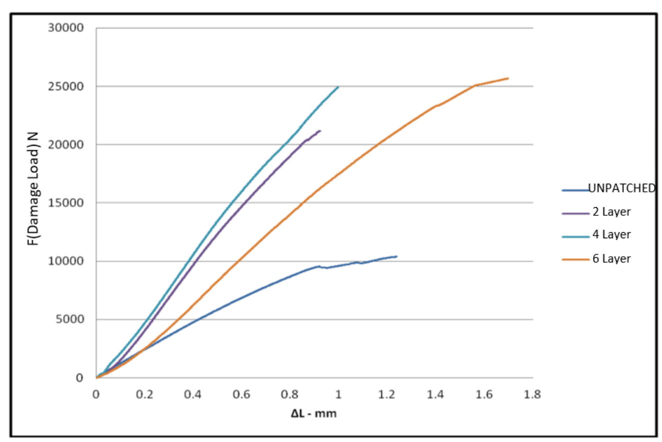

Figure 11. Failure load changes in the number of 2 layers, 4 layers and 6 layers of the patch with a width and length of 60x40 mm.

In Figure 11, it is seen that as the number of layers increases in the adhered patches, the failure loads also increase as the patch width (x) and length (y) are kept constant and the patch thickness (z) increases. Having a width and length of 60x40 mm, the 2-layer samples showed an average failure load of 21100 N, the 4-layer samples showed an average failure load of 24967 N, and the 6-layer samples showed an average failure load of 25764 N.

According to the elliptical damaged samples exposed to tensile load without patch, it is seen that 2-layer samples carry 101% excess load, 4-layer samples carry 138% overload, while 6-layer samples carry 145% excess load.

As a result, as the number of patch layers increases, the patch thickness also increases, the patch strength increases and the failure loads of the samples increase.

IV. RESULTS AND EVALUATION

In this study, in the repair of elliptical damaged laminated composite plates, the effect of patch sizes and patch layer number on tensile stress behavior was investigated experimentally.

The undamaged samples were tested first. Later, when the elliptical damaged specimens were tested, a tensile strength loss of 62% was observed. When the elliptical damaged samples are patched and tested with patches of varying sizes and layer numbers, it is seen that they carry up to 145% more tensile load than the unpatched samples. As a result, it is clear that damage repair with adhesive joints is quite successful.

In addition, it was observed that the failure loads increased with increasing patch width, length and number of layers. Since the increase in the width and length of the patch increases the adhesion strength by increasing the adhesion area, it is thought that the increase in the number of patch layers increases the strength of the patch material, thus increasing the tensile strength.

When 4-layer damaged composite materials are patched with 2-layer patches, the failure loads are lower than the failure loads of the undamaged plates and break from the ellipse section inside the patch. When patched with 4 and 6 layer patches, the failure loads are very close to the failure loads of the undamaged plates and the repaired plates breaks from the outside of the patch. This shows us that damaged materials should be repaired with patches with the same or more layer number.

If the damaged materials are repaired with patches with a lower layer number than their own layer number, it has been observed that the success of the repair decreases. However, if damaged materials are repaired with patches with the same or more layer number, it was seen that the repair was very successful and the repair brought the strength of the damaged area back to the state before the damage, so the patch broke from the outside.

The ruptures from the outside of the patch show that the damage repair with the adhesive joints was so successful that it returned the sample to its undamaged strength, so the sample was broken from the outside of the patch, that is, from the outside of the damaged area.

CONFLICTS OF INTEREST

They reported that there was no conflict of interest between the authors and their respective institutions.

RESEARCH AND PUBLICATION ETHICS

In the studies carried out within the scope of this article, the rules of research and publication ethics were followed.

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