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RESEARCH ARTICLE

The Effect of Damage Line and Patch Dimensions on Tensile Stress Behavior in Repair of Aluminum Plates

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HIGHLIGHTS

- *Effect and importance of damage line and patch dimensions in the repair of aluminum plates*
- *Damaged materials should be repaired with larger patches*
- *Damage repair with adhesive joints brought the strength of the damaged area back to its undamaged strength*
- *Damage repair with adhesive joints is quite successful*

Keywords:

- Alumınum Plates
- Stress Distributions
- Failure Loads
- Adhesive Joints
- Double-Sided Lap Joints

GRAPHICAL ABSTRACT

In this study, in the repair of angled channel aluminum plates, the effects of channel angle and patch sizes on tensile stress behavior were investigated experimentally. For this purpose, aluminum 2024 T3 sheets with angled channels with varying channel angles were prepared. These plates were subjected to tensile loads and their failure loads were investigated experimentally. Then, using DP460 adhesive material, angled channel aluminum 2024 T3 sheets were repaired using double-sided lap joints with aluminum 2024 T3 patches of varying sizes, and the repaired samples were subjected to tensile load, the effect of channel angle and patch size change on failure loads and stress behaviors in repair was also experimentally examined and the success of the repair was evaluated.

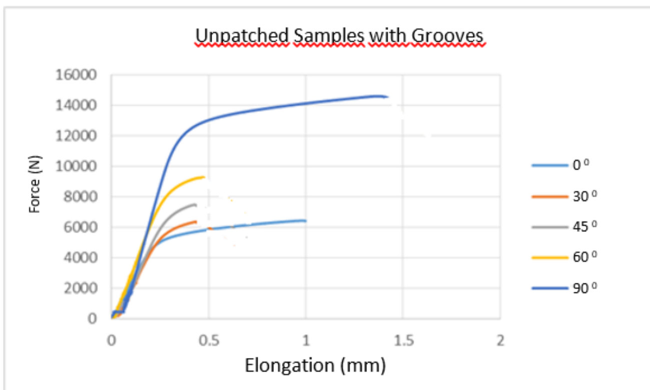

Figure A. Failure load change in damaged and unpatched samples with 0^0, 30^0, 45^0, 60^0 and 90^0 groove angles

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Aim of Article : *In this study, it was aimed to determine the effect of damage line and patch dimensions on tensile stress behaviors in the repair of aluminum plates.*

Theory and Methodology : *Aluminum patches with different dimensions were adhered to the aluminum sheets with different damage lines by using a double-sided lap joint using DP460 adhesive. The tensile tensile strengths of the repaired specimens were investigated experimentally.*

Findings and Results: *As the channel angle increases, the strength increases and damaged plates should be repaired with larger patches.*

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, in the repair of angled channel aluminum plates, the effects of channel angle and patch sizes on tensile stress behavior were investigated experimentally. For this purpose, aluminum 2024 T3 sheets with angled channels with varying channel angles were prepared. These plates were subjected to tensile loads and their failure loads were investigated experimentally. Then, using DP460 adhesive material, angled channel aluminum 2024 T3 sheets were repaired using double-sided lap joints with aluminum 2024 T3 patches of varying sizes, and the repaired samples were subjected to tensile load, the effect of channel angle and patch size change on failure loads and stress behaviors in repair was also experimentally examined and the success of the repair was evaluated.

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

I. INTRODUCTION

Today, under fatigue and tensile loads, due to many properties such asv high strength, corrosion resistance, easy shaping, durability, strength, lightness, good thermal and electrical conductivity, etc., the use of aluminum materials is increasing. Aluminum is light. It weighs only one third of the weight of a steel material of the same volume. 2024 aluminum alloy is one of the hardest, having highest elasticity modulus and strength values among aluminum alloys. It is widely used in the automotive industry, wagon construction, ammunition industry, aircraft fuselage and wings, orthopedic soles, rivets and traction wheels Where specific strength (yield stress / density) and specific modulus of elasticity (modulus of elasticity / density) are important. By applying heat treatment to 2024 Al-alloy, its mechanical properties can be increased significantly. Among them, 2024-T3 alloy finds wide usage area especially due to its high strength. In buildings where materials 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 sector, 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, they are increasingly preferred due to their uniform stress distribution, lightness, high fatigue strength and

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development of increasingly stronger adhesives.

In this study, in the repair of angled channel aluminum plates, the effects of channel angle (the effect of damage line) and patch sizes on tensile stress behavior were investigated experimentally. For this purpose, aluminum 2024 T3 sheets with angled channels with varying channel angles were prepared. These plates were subjected to tensile loads and their failure loads were investigated experimentally. Then, using DP460 adhesive material, angled channel aluminum 2024 T3 sheets were repaired using double-sided lap joints with aluminum 2024 T3 patches of varying sizes, and the repaired samples were subjected to tensile load, the effect of channel angle and patch size change on failure loads and stress behaviors in repair was also experimentally examined and the success of the repair was evaluated.

In recent years, many studies have been carried out on this subject. For example, Ayaz et al. [1] investigated the behavior of patched AA 2024-T3 aluminum parts with double reinforced embedded spring steel patches under four-point bending and the effect of part thickness on bonding joints by experimental and finite element method (FEM). SBT 9244 was used as the adhesive. It has been observed that the thickness of the part has a significant effect on the stress distribution. Ergün [2] studied the tensile properties of repairing elliptically damaged aluminum plates with composite patch experimentally and numerically. 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. Ramji et al. [5], 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. Soy [6], with the help of computer aided modeling, worked on the adhesive repair of Al 2024-T3 alloy plate with composite patch. Tensile and bending stress behaviors were investigated by experimental and numerical analysis. Tek [7] studied stress analysis in single and double lap adhesive joints. Comparisons were made in failure loads with experimental and numerical analyzes. Gültekin et al. [8] 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. [9] 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. [10] 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. [11] 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. [12] 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 [13], 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. [14] 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. [15], 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, aluminum 2024 T3 material was used as a patch material and adhered material to form the double-sided lap joint. The adhered and patch materials to be used are cut according to their dimensions. The adhered materials were cut from Aluminum 2024 T3 sheets, 140x40x1 mm in size, with angled grooves. The patches are from the same plates, it has been cut in dimensions of 40x40 mm, 40x50 mm, 40x60 mm. Mechanical properties of aluminum 2024 T3 material are given in Table 1.

Table 1.

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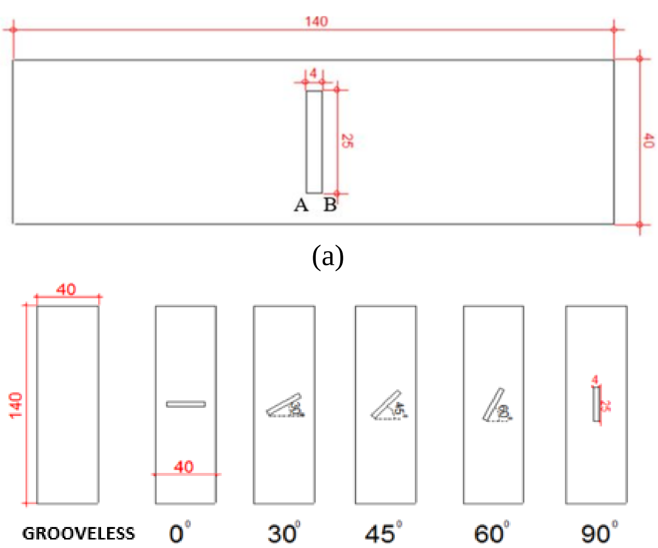
Mechanical properties of bonded and patch material (Aluminum 2024 T3)

PROPERTY	VALUE	UNIT
Modulus of Elasticity	73.1	GPa
Shear Module	28	GPa
Poisson Ratio	0.33	-
Yield Strength	345	MPa
Tensile Strength	483	MPa
Shear Strength	283	MPa
Elongation at Break	18%	-
Vickers Hardness	137	-

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. Mechanical properties of adhesive material are given In Table 2, the shape and dimensions of the damaged samples and patches are given in Figure 1, Figure 2 and Table 3.

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

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



(a)

(b)

Figure 1. (a) 0 ° slotted AA-2024 T3 aluminum plate dimensions (b) grooveless , 0 °, 30 °, 45 °, 60 ° and 90 ° angle grooved sample sizes

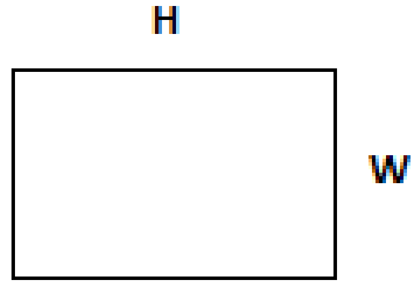


Figure 2. AA-2024 T3 aluminum patch

Table 3.
Sample parameters and values

EXPERIMENT SAMPLE DIMENSIONS				
Aluminum 2024-T3 Base Material		Aluminum 2024-T3 Patch Material		
Sheet Size (mm)	Placement angles of 4x25 mm channels	Patch Sizes		
		H (mm)	W (mm)	Thickness (mm)
40x140x1	0 °	40	40	1
		50		
		60		
	30 °	40		
		50		
		60		
	45 °	40		
		50		
		60		
	60 °	40		
		50		
		60		
	90 °	40		
		50		
		60		

Patched lap joints obtained using DP460 adhesive material are shown schematically in Figure 3 and Figure 4.

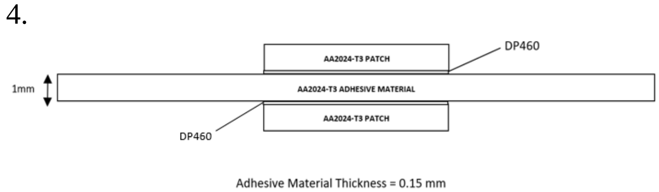
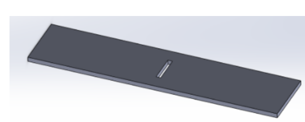


Figure 3. Schematic representation of the prepared test samples.



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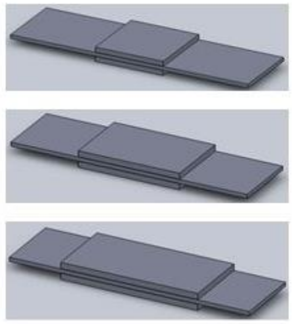

Figure 4. The resulting double-sided lap joints

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 specimens first, then on unpatched specimens with angled grooves, and then on specimens patched with double-sided lap joints with angled grooves. 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.

Figure 6 shows the strain of a patched specimen when subjected to load between the jaws of the tensile testing device, while recording the load on it and the elongation by means of the extensiometer. The 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.

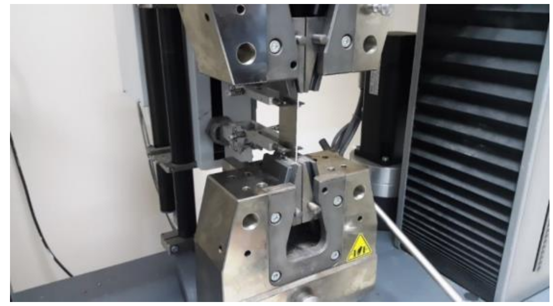

Figure 6. The sample under load

Table 4.

Failure loads and damage types of lap joints

Groove Angles	H (mm)	Experimental Failure Load (N)	DAMAGE TYPES
Grooveless (No Damage)	Unpatched	19080	**A**
0^0	0 Unpatched	6280	**B**
30^0		6400	**B**
45^0		7320	**B**
60^0		9200	**B**
90^0		14520	**B**
0^0	40	17720	**D**
30^0		18000	**C**
45^0		18200	**D**
60^0		18400	**C**
90^0		18600	**C**
0^0	50	18120	**C**
30^0		18400	**D**
45^0		18480	**D**
60^0		18600	**C**
90^0		18840	**C**
0^0	60	18560	**C**
30^0		18640	**C**
45^0		18760	**C**
60^0		18800	**D**
90^0		19000	**C**

A : 3 samples are failured through 45^0 to the pulling direction
B : 3 samples are failured at A points of AB lines
C : 3 samples are failured in patch region
D : 2 of 3 samples are failured in patch region, 1 from out of patch

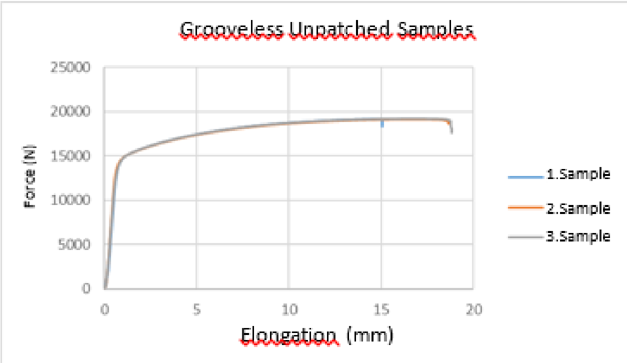

Figure 7. Failure load variation of 3 undamaged and unpatched samples.

In Figure 7, an average damage load of 19080 N is seen in the tests performed without damage or patch.

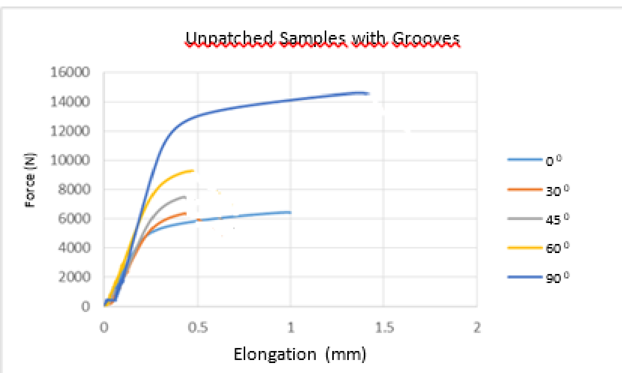

Figure 8. Failure load change in damaged and unpatched samples with 0^0, 30^0, 45^0, 60^0 and 90 ^{0} groove angles.

Figure 8 shows that, Failure load in damaged and unpatched samples with 0^0 groove angle is 6280 N, with 30^0 6400 N, with 45^0 7320 N, with 60^0 9230 N and with 90^0 14520 N.

In damaged samples, there is 67% strength loss for 0^0, 66% for 30^0, 62% for 45^0, 52% for 60^0 and 24% for 90^0.

The highest strength loss was 67% for the 0^0 groove angle and the lowest strength loss was 24% for the 90^0. That is, as the groove angle increases, the strength increases. The reason for this is that as the groove angle increases, the area in the section resisting the load also increases.

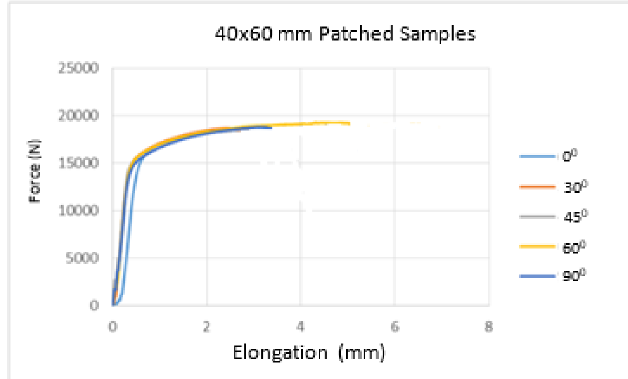

Figure 9. Failure load changes with groove angle changes for 40x60 mm patch.

In the experiments performed with 40x60 mm patch size in Figure 9, 18560 N failure stress for 0^0, 18640 N for 30^0, 18760 N for 45^0, 18800 N for 60^0 and 19000 N for 90^0 was seen.

As the patch size is kept constant at 40x60 mm and the groove angle values increase, the strength increases due to the increase in the area in the section that resists the load.

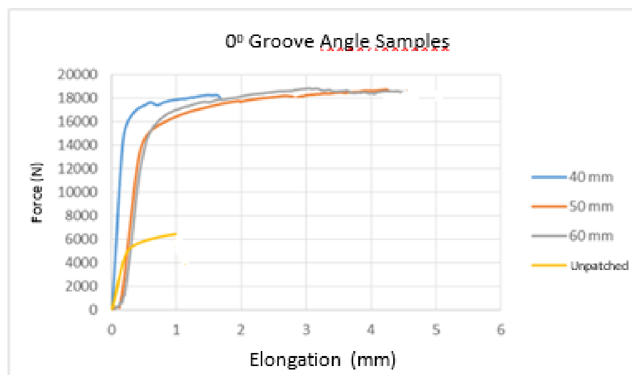

Figure 10. Failure load variation with patch size changes in samples with 0^0 groove angle.

Figure 10 shows that for groove angle 0^0, the unpatched failure load is 6280 N, for 40 mm patch length is 17720 N, for 50 mm 18120 N, and for 60 mm 18560 N.

Compared to unpatched damaged specimens with angled channels subjected to tensile loads, it is seen that specimen with 40 mm patch length carries 182% more load, with 50 mm carries 188% more load, with 60 mm carries an excess of 195%.

As a result, it was observed that the failure loads of the samples increased as the patch size increased, as the adhesion area increased.

IV. RESULTS AND EVALUATION

In this study, in the repair of angled channel aluminum plates, the effects of patch size and channel angle change on the tensile stress behavior was investigated experimentally.

The undamaged samples were tested first. As expected, samples are failured through 45^0 to the tensile load direction.

When the angled channel aluminum samples are tested, the damaged samples show 67% strength loss for 0^0, 66% for 30^0, 62% for 45^0, 52% for 60^0, and 24% for 90^0. That is, as the channel angle increases, the strength increases. The reason for this is that as the channel angle increases, the area in the section resisting the load also increases. Samples are failured at A points of AB lines which is the most critical point due to its proximity to the edge and due to the small load bearing area.

When patched samples with varying groove angles and patch sizes are tested, it is seen that they carry up to 195% more tensile load than unpatched samples. As the patch size is kept constant and the groove angle values increase, the strength increases due to the increase in the area in the section that resists the load.

Compared to unpatched damaged specimens with angled channels subjected to tensile loads, it was seen that specimen with longer patch lengths carries more loads. The failure loads of the samples increased as the patch size increased, as the adhesion area increased.

Some of the 40x40, 40x50 and 40x60 mm patched samples were broken from inside of the patch and some from outside of the patch. 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.

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.

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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