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# NUMERICAL AND EXPERIMENTAL INVESTIGATION ON THE REPAIR IMPACT OF ARROW-SHAPED AND HEXAGONAL GLASS-EPOXY COMPOSITE PATCHES

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**Abstract**

Composites as materials with superior characteristics have proved their effectiveness in maintaining of damaged components, especially in aeronautical applications. Within the current research, the arrow-shaped and hexagon glass-epoxy composite patches with fibers orientations angles of 0,90 and -45,45 are employed with the aim of repairing the cracked aluminum alloy 7075 specimens. Total number of 28 one-sided repaired aluminum samples with 30 mm of crack length situated within the center, are prepared to undergo uniaxial tensile loading using the 600 KN santam testing machine. Additionally, to the experimental tests, the Abaqus software is employed so on simulate the testing conditions numerically with XFEM (Extended finite element method) technique. Findings indicate that the arrow-shaped composite patches have higher efficiency of repair and sturdiness compared to ones with hexagonal geometry. Also, by decrease in measurements of the repair patch geometry, the upper tensile load is handled. Specimens repaired with glass-epoxy composites fibers orientation angle of -45,45 degree are extended more, but can withstand lower tensile loading.

**Key Words:** glass-epoxy composite, Arrow-shaped, Hexagon patch, crack, extended finite element method, aluminum alloy 7075, uniaxial tensile test,

## 1. INTRODUCTION

Makwana and shaikh revealed that the composite patch as an honest method of repair and reinforcement decreases the strain and its intensity [1]. Hosseini et el. concluded glass-epoxy patch repair doubled the fatigue lifetime of two-sided patched specimens [2]. The Composite patching was considered an on spot practical technique for repairing common and regular damages within the aluminum aircraft structures [3]. Impacts of moisture, temperature besides other contributing environmental factors determined to be the varied reasons directly influencing the repair durability of adhesive patching joints [4]. Also, Composite patching proved its capability for underwater repair applications of aluminum structures under tensile and bending loading [5]. Khalid Saeed and Muhammad Abid studied the performances of bonded composite patch as compared to metallic ones on aluminum alloy 2024 samples. They concluded that the fatigue lifetime of the specimens repaired by bonded composite patches enhanced approximately for quarter-hour [6]. Yu Zhiqiang et el. focused on the adhesive repair modification of cracked aluminum samples using carbon-aramid fiber/epoxy sandwich composite patch. It absolutely was found that the composite sandwiches with 3 layers of fibers increased the effectiveness of repair for both tensile and bending loads 86% and 190% respectively [7]. The composite patch repair on aluminum alloy 7075 specimens using graphite-epoxy at high stress levels when applying constant load caused delay in their fatigue life [8]. The rectangular shaped patches found to be more practical compared to oblique and elliptical geometries {[9], [10]}. The present study has numerically and experimentally investigated the comparison of the features of arrow-shaped and hexagonal glass-epoxy composite patches on repairing cracked aluminum alloy 7075 specimens.

### *1.1 Methodologies*

In the experimental part, the 600 KN Santam testing machine is employed to perform real tensile loading on the samples (Figure.1). Also, Abaqus software is used to numerically analyze and simulate the testing conditions.

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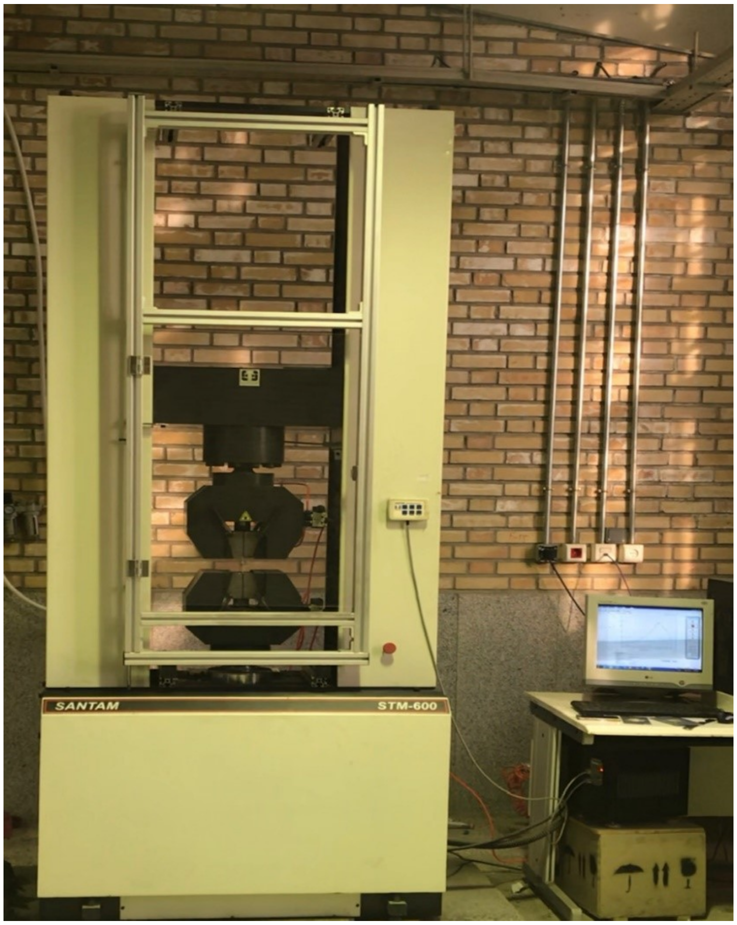


Figure 1: The 600 KN Santam Testing Machine

### *1.1.2 Experimental Method*

Twenty-eight cracked specimens made of aluminum alloy 7075 with the width and length of 80 and 150 mm were subjected to uniaxial tensile loading. These samples were repaired by glass-epoxy composite patches with hexagonal and arrow-shaped geometries that had 0,90 and -45,45 fibers orientations angles. Repair patches themselves were prepared in different height, length and alpha angle measurements. Alpha indicates the half of an angle between both adjacent sides in the left and right directions. SL has been allocated for the length sides of both arrow head and hexagonal composite patches. In addition, L represents the horizontal distance as the length and H indicates the height of the patches (Table.1). Repaired aluminum panels were positioned vertically between the lower and upper crossheads in the load-cell of the testing machine (Figure.2). The required information relating to shape and size of the samples such as: length, width, area and also the loading type were taken into account using the operating user's software of the Santam testing machine. Maximum tensile load and extension obtained from the experimental tensile tests before the failure for each specimen were monitored (Table.1). Also, the Force-Displacement curves were plotted.

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Table 1: Measurements and Specifications for Aluminum Samples

| Specimen Number | Geometry Type | Alpha Angle (Degree) | Side Length (mm) | Horizontal Length L (mm) | Vertical Length H (mm) | Glass Fibers Orientations Angle (degree) | Maximum Tensile Load (Newton) | Maximum Displacement Extension (mm) |
|---|---|---|---|---|---|---|---|---|
| 1 | Hexagonal | 50 | 18 | 35 | 28 | 0,90 | 13759 | 3.403 |
| 2 | Hexagonal | 52 | 28 | 55 | 45 | 0,90 | 12434 | 3.362 |
| 3 | Hexagonal | 55 | 35 | 60 | 58 | 0,90 | 13935 | 3.327 |
| 4 | Hexagonal | 64.5 | 32 | 40 | 58 | -45,45 | 14627 | 3.690 |
| 5 | Hexagonal | 64.5 | 33 | 42 | 60 | 0,90 | 8505 | 2.445 |
| 6 | Hexagonal | 64 | 33 | 45 | 60 | -45,45 | 9418 | 2.363 |
| 7 | Hexagonal | 60 | 33 | 50 | 60 | -45,45 | 8638 | 2.515 |
| 8 | Hexagonal | 30 | 13 | 35 | 12 | 0,90 | 14303 | 3.690 |
| 9 | Hexagonal | 30 | 13 | 35 | 12 | -45,45 | 9167 | 2.927 |
| 10 | Hexagonal | 20 | 18 | 52 | 12 | -45,45 | 11713 | 3.940 |
| 11 | Hexagonal | 20 | 18 | 50 | 12 | 0,90 | 8167 | 2.347 |
| 12 | Hexagonal | 20 | 18 | 52 | 12 | -45,45 | 10786 | 3.010 |
| 13 | Hexagonal | 45 | 20 | 45 | 32 | 0,90 | 13935 | 3.608 |
| 14 | Hexagonal | 40 | 22 | 55 | 28 | 0,90 | 12052 | 3.280 |
| 15 | Hexagonal | 40 | 22 | 55 | 30 | -45,45 | 11904 | 3.267 |
| 16 | Hexagonal | 40 | 22 | 50 | 28 | -45,45 | 11434 | 3.176 |
| 17 | Arrow | 22.89 | 18 | 53 | 12 | 0,90 | 11684 | 3.224 |
| 18 | Arrow | 33 | 22 | 55 | 24 | 0,90 | 8373 | 2.442 |
| 19 | Arrow | 45 | 25 | 60 | 36 | -45,45 | 12670 | 3.362 |
| 20 | Arrow | 46.5 | 28 | 60 | 42 | 0,90 | 12096 | 3.280 |
| 21 | Arrow | 60 | 23 | 35 | 40 | 0,90 | 13965 | 3.608 |
| 22 | Arrow | 70 | 30 | 35 | 54 | 0,90 | 13479 | 3.526 |
| 23 | Arrow | 62.5 | 30 | 42 | 54 | 0,90 | 13935 | 3.533 |
| 24 | Arrow | 60 | 32 | 60 | 54 | -45,45 | 12567 | 3.362 |
| 25 | Arrow | 57 | 22 | 38 | 42 | 0,90 | 15039 | 3.772 |
| 26 | Arrow | 65 | 28 | 35 | 48 | -45,45 | 13361 | 3.444 |
| 27 | Arrow | 65 | 30 | 40 | 56 | -45,45 | 9462 | 2.656 |
| 28 | Arrow | 65 | 30 | 40 | 5.6 | 0,90 | 12684 | 3.362 |

Figure 2: Positioning the Sample in the Load-cell

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### *1.2.1 Numerical Simulation*

The Abaqus software version 6.14 2021 was employed to numerically analyze and simulate the uniaxial tensile loading conditions for the aluminum samples repaired and reinforced by glass-epoxy composite patches. Extension displacements obtained from the real experimental tests at failure point in which the specimens were no longer able to withstand the maximum tensile load was used to precisely determine the highest level of loading in numerical simulations by XFEM (Extended Finite Element Method). Two-dimensional sketches of the optimum hexagonal and arrow head composite patches with capacity of withstanding the maximum tensile load were designed (Figures 3&4).

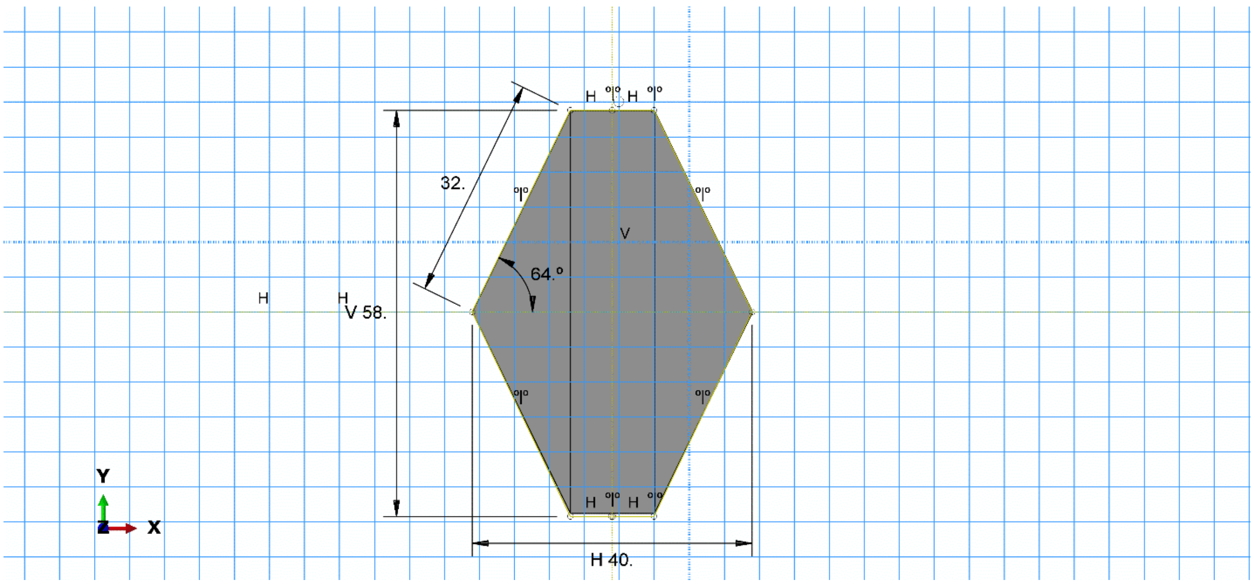


Figure 3: The 2D Sketch of the Hexagonal Composite Patch Used for Repairing the Aluminum Specimen Number 4

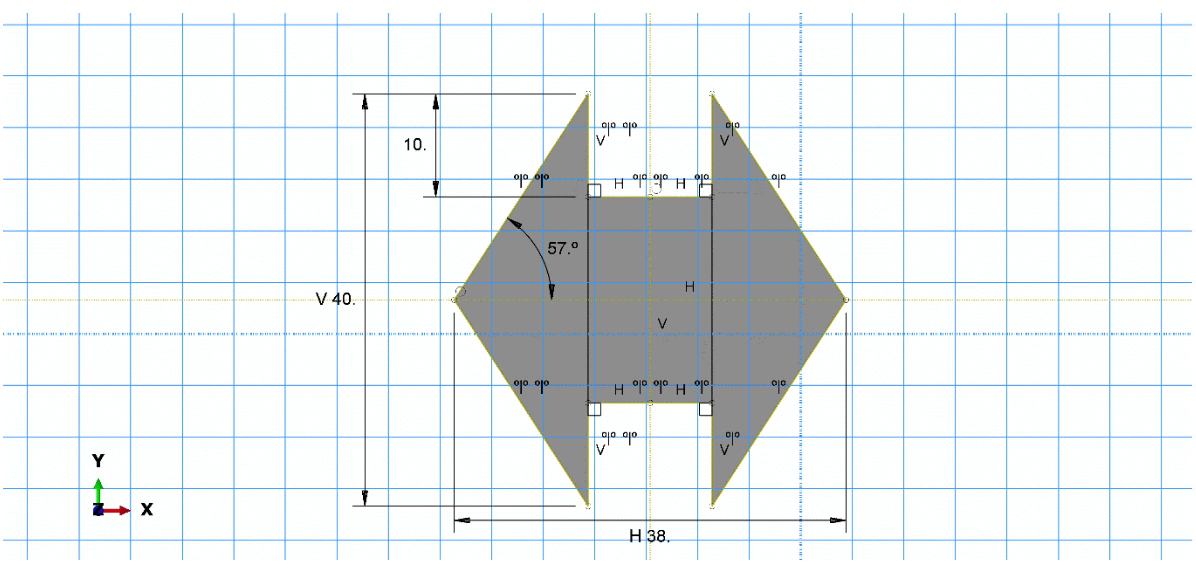


Figure 4: The 2D Sketch of the Arrow-shaped Composite Patch Used for Repairing the Aluminum Specimen Number 25

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### *1.2.2 Property Determination*

Real specifications of aluminum alloy 7075 from the literature such as the Young's Modulus and Poisson's Ration were applied for the panel (Table 2).

Table 2. Material Characteristics of Aluminum Alloy 7075

| Layer Name | Poisson's Ratio | Young's Modulus |
|---|---|---|
| Aluminum alloy 7075 | 0.33 | 71.7 (GPa) |

Also, the engineering constants for the glass-epoxy composite patch considered as Table 3 shows.

Table 3. Glass-Epoxy Material Specifications

| E1 | E2 | E3 | G12 | G13 | G23 | Nu12 | Nu13 | Nu23 |
|---|---|---|---|---|---|---|---|---|
| 40e9 | 10e9 | 10e9 | 3.8e9 | 3.8e9 | 3.4e9 | 0.30 | 0.30 | 0.40 |

The glass fibers orientation angles of the plies for hexagonal and arrow-shaped composite patches used to repair the samples number 4 and 25 are -45,45 and 0,90 respectively (Figures 5 & 6).

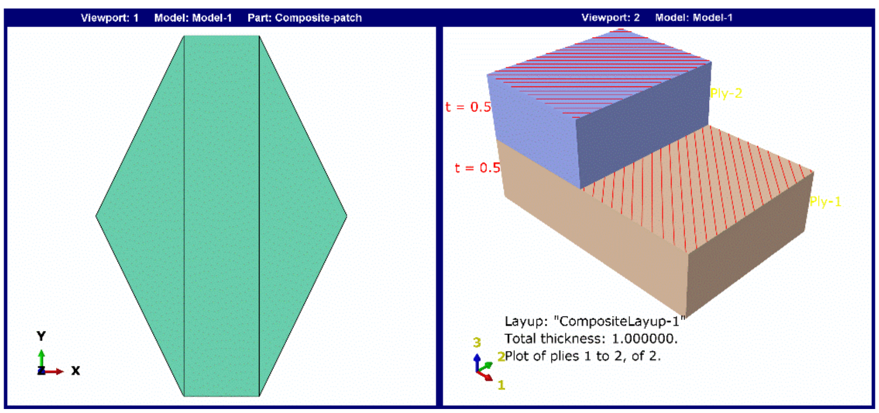


Figure 5: The Orientation of Plies for Hexagonal Patch in Specimen Number 4

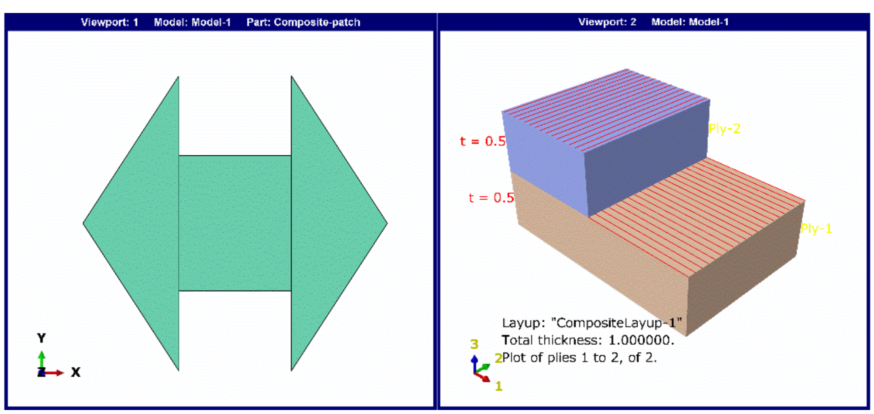

Figure 6: The Orientation of Plies for Arrow-shaped Patch in Specimen Number 25

### *1.2.3 Assembling*

After defining the location of the crack, composite patches were employed to repair the cracked samples number 4 and 25 (Figures 7 & 8).

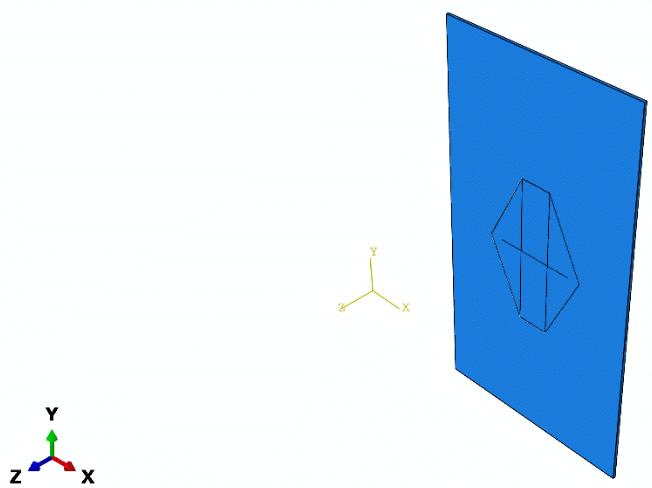


Figure 7: The Assembled Specimen Number 4 Repaired with Hexagonal Glass -Epoxy Composite Patch

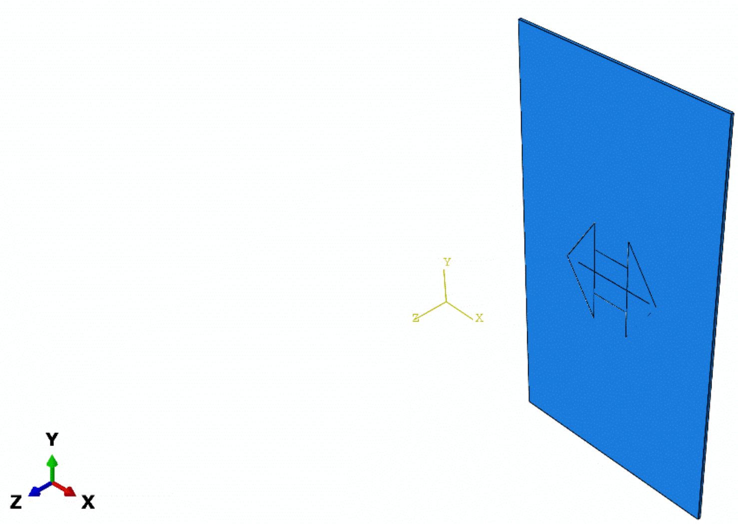


Figure 8: The Assembled Specimen Number 25 Repaired with Arrpw-Shaped Glass-Epoxy Composite Patch

### *1.2.4 Meshing*

The Composite patches with hexagonal and arrow head geometries were partitioned and meshed by applying 0.2 and 2 for absolute value and the approximate global size respectively (Figures 9 & 10).

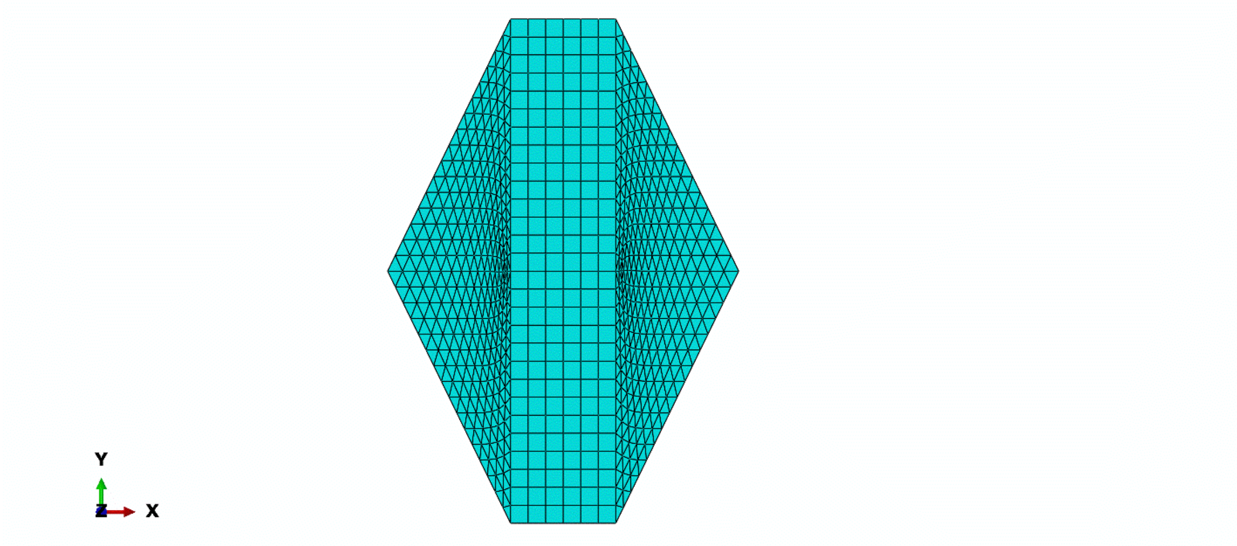


Figure 9: The Meshed and Partitioned Hexagonal Glass-Epoxy Composite Patch

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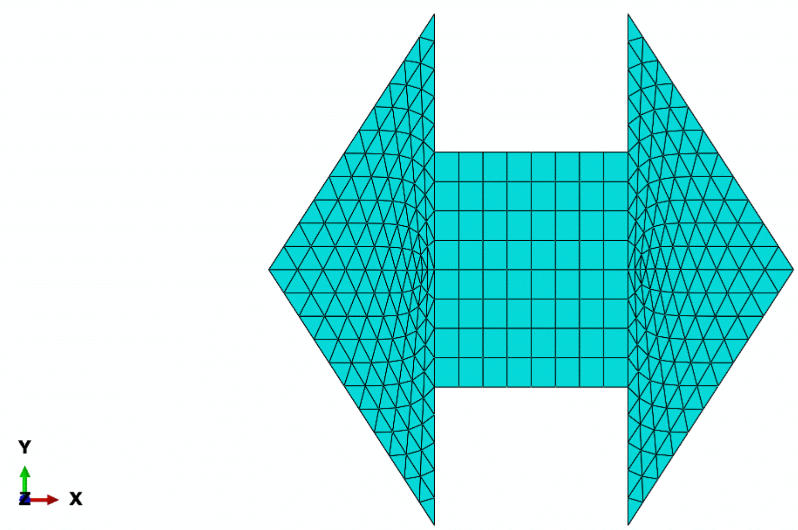


Figure 10: The Meshed and Partitioned Glass-Epoxy Arrow-shaped Composite Patch

After meshing the composite repair patches, they were installed on the cracked specimens (Figures 11&12). It should be noted that the linear S4R and S3 element types were allocated for meshing the partitioned rectangular and triangular geometries of the repair patches. Also, hex technique was used to mesh the aluminum plate.

Figure 11: The Fully-Meshed Repaired Cracked Aluminum Specimen Number 4

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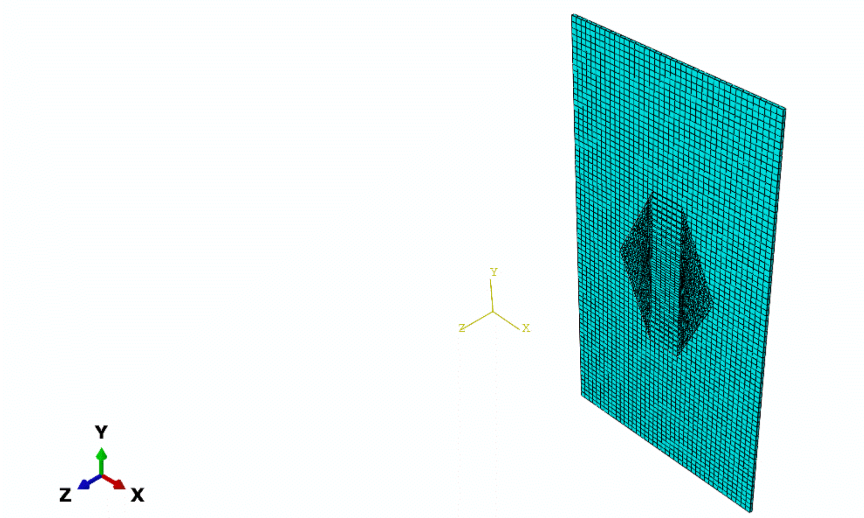


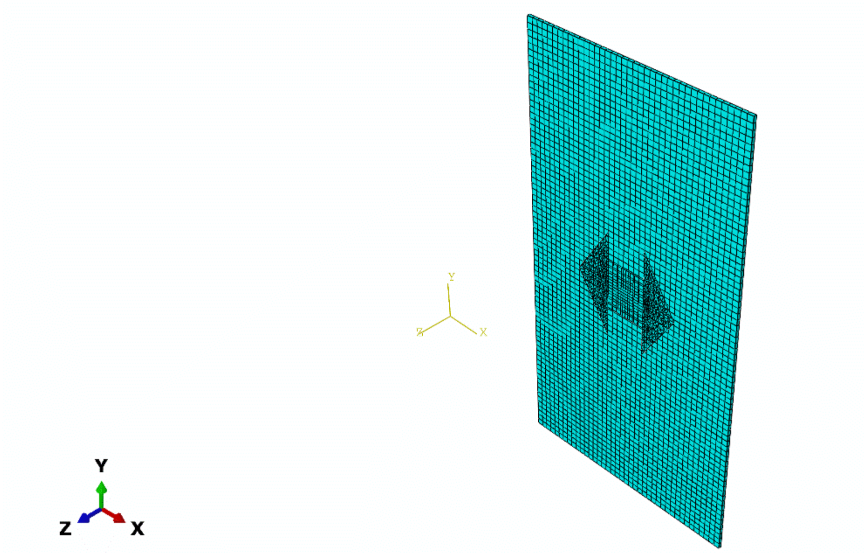


Figure 12: The Fully-Meshed Repaired Cracked Aluminum Specimen Number 25

### *1.2.5 Loading and Boundary Conditions*

The top and end sets were created to simulate the testing conditions during which the lower crosshead of the testing machine was fixed and only the upper head was moving and operating along Y direction. Displacements considered for samples number 4 and 25 are 3.690 and 3.772 mm respectively (Figures 13 & 14).

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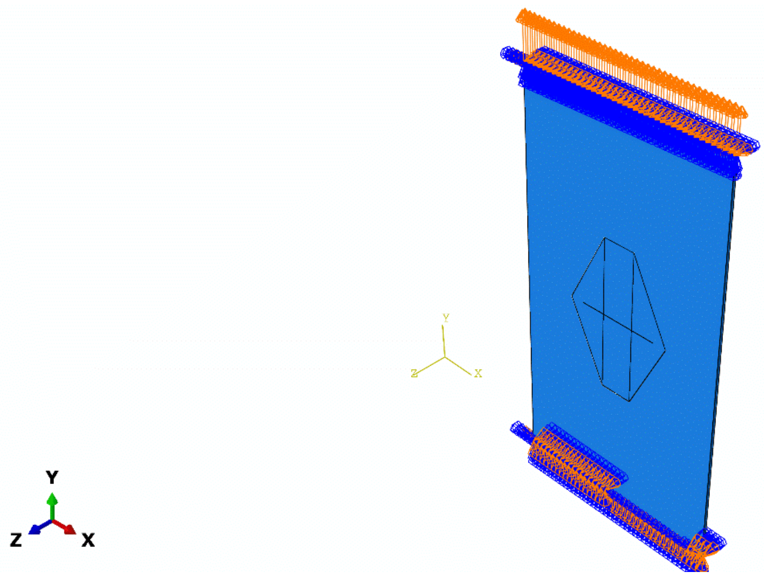


Figure 13: Loading and Boundary Conditions for Specimen Number 4 Repaired with Hexagonal Patch

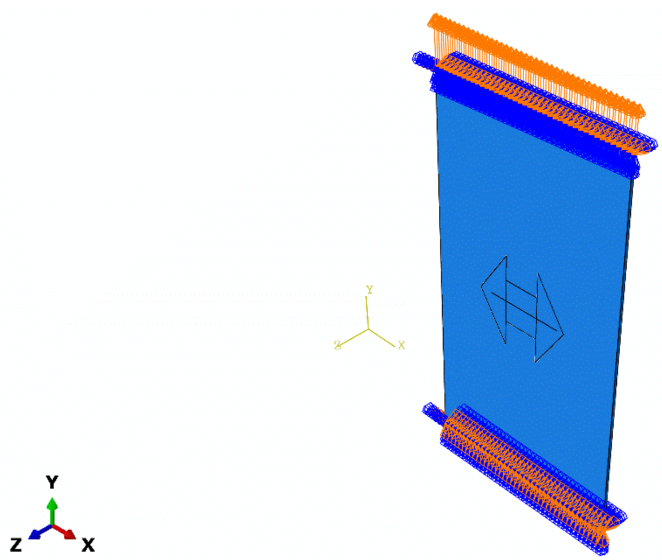


Figure 14: Loading and Boundary Conditions for Specimen Number 25 Repaired with Arrow-shaped Patch

*1.2.6 Visualization*

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Lastly, the simulated uniaxial tensile loading tests were performed for the repaired aluminum samples number 4 and 25. The results of numerical simulations of Misses stress distribution for both specimens and their Force-Displacement linear graphs were monitored and reported (Figures 15, 16, 17 & 18).

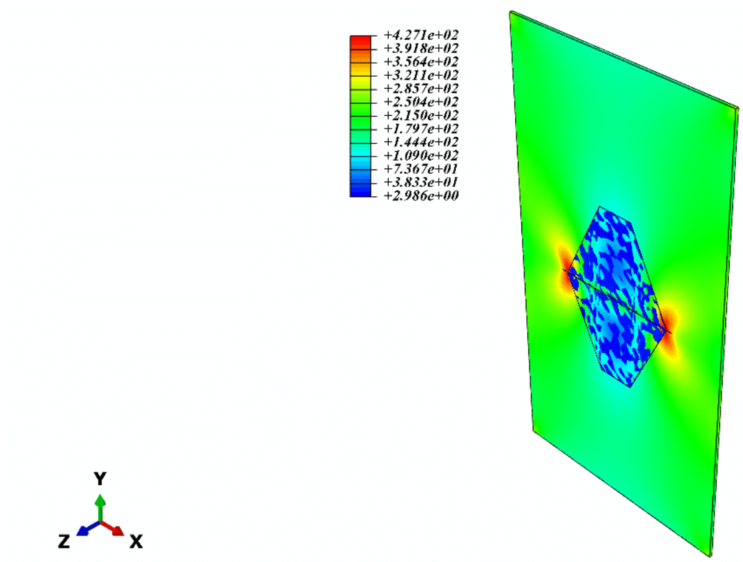


Figure 15: Misses Stress Distribution for Specimen Number 4 Repaired with Hexagonal Patch

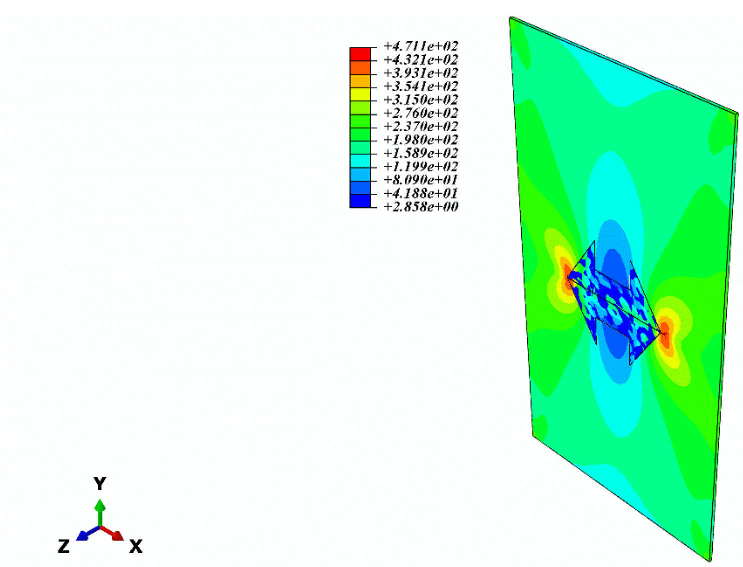


Figure 16: Misses Stress Distribution for Specimen Number 25 Repaired with Arrow-shaped Patch

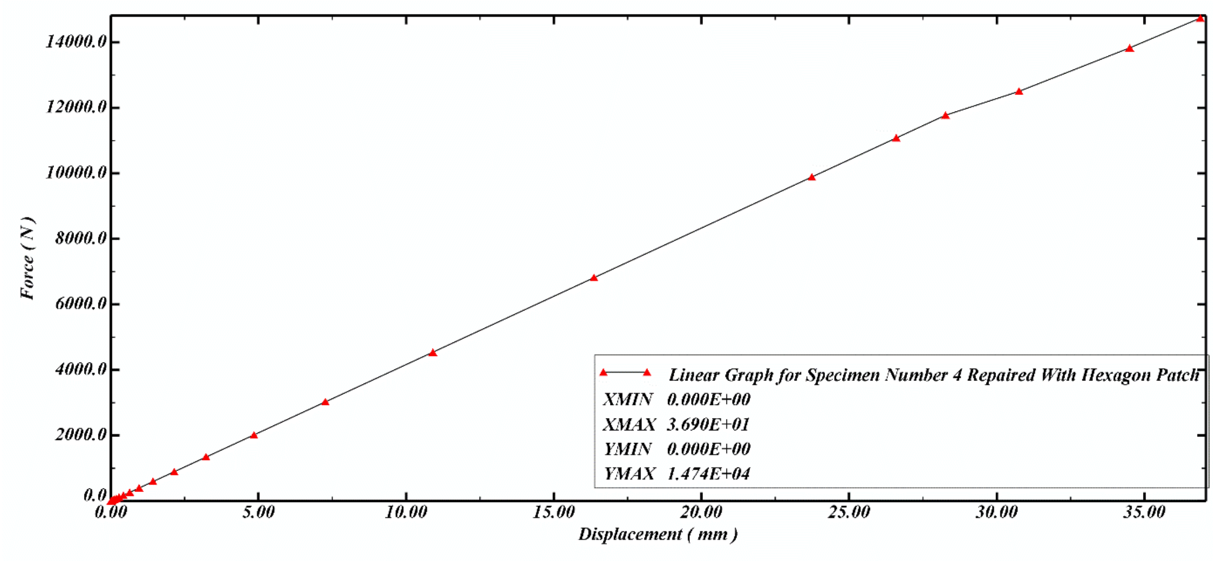


Figure 17: The Force-Displacement Curve for Specimen Number 4

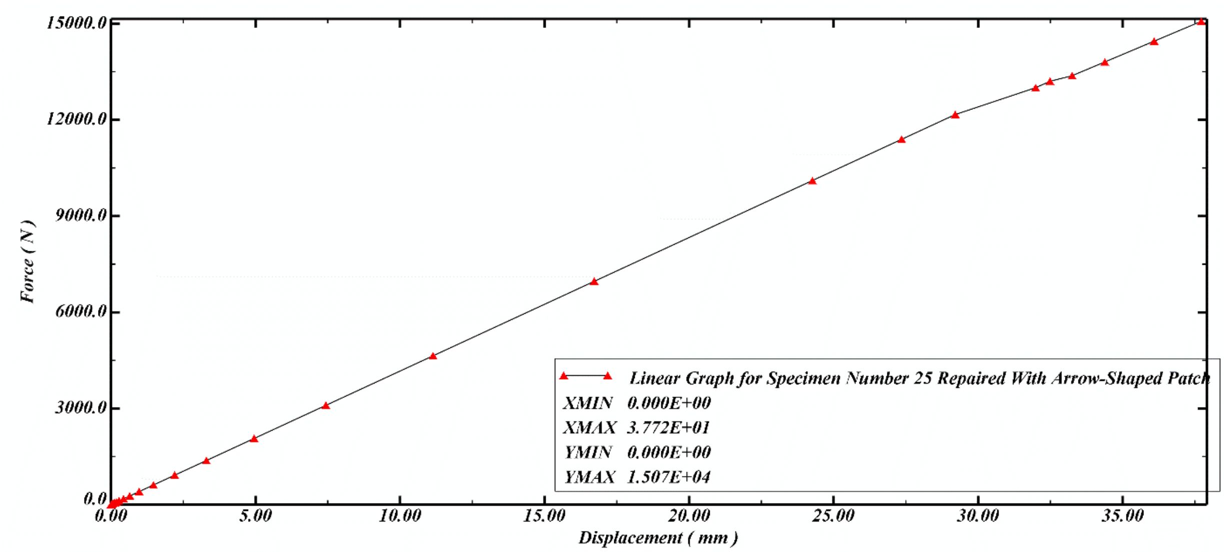


Figure 18: The Force-Displacement Curve for Specimen Number 25

## 2. Results

1. Findings showed that the glass-epoxy composite patches with arrow head geometry are superior to the ones with hexagonal shape.
2. Samples number 4 and 25 had the highest level of durability of repair and withstanding uniaxial tensile loading.
3. By decrease in the measurements of the patch, the efficiency of the repair significantly rose.

4. Patches with fibers orientation angle of -45,45 degree had the maximum displacement extension while the ones with 0, 90 angle of fibers orientation handled the maximum tensile loading.

## 3.Discussion and Conclusions

In this study the repair impacts of arrow-shaped and hexagonal composite patches with different glass fibers orientation angles on cracked aluminum alloy 7075 plates were investigated. The 600KN Santam testing machine was employed to perform the experimental tensile tests. Then, each of cracked specimen was numerically simulated with Abaqus software using the extended finite element method. The validation of experimentally obtained results indicated the least error percentage in comparison to numerical ones. It has been found out that composite patching technique highly enhances the durability of repair in aluminum structures. To conclude, with the aid and contribution of technology, failure of the damaged aluminum components and repairing them are highly predictable under most of the conditions.

## Declarations

*Ethical approval and consent to participate:*

Not applicable.

*Consent for publication:*

*Not applicable.*

*Availability of data and materials*:

All the required data are provided as within tables and also numbered sections explaining how the procedure or process was conducted.

*Competing interest:*

The author states no conflict of interests as the only creator of the manuscript.

Funding:

The author states no funding involved

*Author's contributions:*

The author states that the design of the study, collection, analysis and interpretation of data in writing the manuscript belongs to him.

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