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Design and Analysis of Aluminums Sheet Delamination Repair using Composite Materials

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***Abstract*—This abstract presents a Tensile approach for the repair of cracked aluminum structures through the integration of advanced composite materials, specifically epoxy carbon with a Young's Modulus of 395 GPa, and a copper metal matrix composite (MMC) alloy. The study employs the ANSYS Static Structural analysis to evaluate the structural integrity and performance of the repaired aluminum components. The cracked aluminum structures are modeled, and the epoxy carbon composite is strategically applied to the damaged regions. Additionally, a copper MMC alloy is introduced to enhance the mechanical properties of the repaired sections. The ANSYS Static Structural analysis provides critical insights into stress distribution, deformation, and overall structural response, aiding in the optimization of the repair design. This innovative approach aims to extend the service life of aluminum structures by leveraging the synergistic benefits of epoxy carbon and copper MMC composites, demonstrating the potential for enhanced durability and performance in aerospace, automotive, and other engineering applications.**

***Keywords*— Aluminum repair, Epoxy carbon composite, Copper MMC, Structural analysis, Finite element method.**

I. INTRODUCTION

The repair and rehabilitation of cracked aluminum structures have become increasingly vital in various engineering applications, including aerospace and automotive industries. In this study, we explore an innovative approach to address such structural issues by incorporating advanced composite materials, namely epoxy carbon with an impressive Young's Modulus of 395 GPa, and a copper metal matrix composite (MMC) alloy. The combination of these materials aims to not only mend existing cracks but also enhance the overall mechanical properties of the repaired aluminum components. The ANSYS Static Structural analysis is employed as a powerful tool to conduct a thorough evaluation of the repaired structures. This analysis provides valuable insights into stress distribution, deformation, and the structural response of the composite-reinforced aluminum. Furthermore, the study includes an optimization phase where ANSYS is utilized to refine and enhance the design based on the analysis results, ensuring the repaired structures meet stringent safety and performance criteria. This research represents a significant step towards advancing the durability and longevity of aluminum structures, showcasing the potential of epoxy carbon and copper MMC composites in structural repair applications. Aluminum structures and aircrafts are subjected to various static and dynamic loads during their service life.it is uneconomical to replace the aircraft part due to short budgets and higher procurement costs

A. Objective

- To Identify and characterize the existing cracks in aluminum structures to understand the extent of damage.
- To evaluate the mechanical properties of epoxy carbon (395 GPa Young's Modulus) and copper MMC alloy to ensure suitability for structural repair and enhancement.
- To formulate a comprehensive repair strategy integrating epoxy carbon and copper MMC alloy to effectively address and mitigate the identified cracks.
- To Utilize ANSYS software to create detailed 3D models of the cracked aluminum structures and implement simulation setups for Static Structural analysis.
- To conduct rigorous ANSYS Static Structural analysis to evaluate stress distribution, deformation, and structural response of the repaired aluminum structures.
- To Utilize ANSYS optimization tools to refine the repair design based on analysis results, ensuring optimal performance and structural integrity.
- To validate the effectiveness of the proposed repair solution by comparing simulation results with established manufacturing modal by UTM Testing it.

II. ANALYTICAL CALCULATION & DESIGN

A. Method.

- Analytical & Modeling of Cracked Aluminum Structure
- Material Selection and Assignment
- Composite Application
- Meshing and Boundary Conditions
- Static Structural Analysis
- Optimization of Repair Design
- Experimentation & Testing
- Result Evaluation

B. Analytical Calculation

To find the out the mass of the part body

$$M = \rho * L * W * H \ in \ Kg$$

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$$\boldsymbol{M = 2770 * 0.3 * 0.06 * 0.001 = 0.04986\ Kg}$$

M is the mass,

- ρ is the density (units: mass per unit volume, e.g., kg/m³), = 2770 Kg/m^3
- L is the length of the rectangular object = 300 mm = 0.3 m
- W is the width of the rectangular object = 60 mm = 0.06 m
- H is the height of the rectangular object = 1 mm = 0.001 m

$$I = \frac{1}{12} * b * h^3 = \frac{1}{12} * 60 * 1^3 = 5\ mm^4$$

Bending moment formula

$$\boldsymbol{M = \frac{F * L}{4} = \frac{200 * 50}{4} = 2500\ N - mm}$$

$$\boldsymbol{\sigma b = \frac{M * Y}{I} = \frac{2500 * 0.5}{5} = 250\ MPa}$$

$$M = Maximum\ Bending\ momenti\ n - mm$$

$$Y = \frac{Thickness}{2} = \frac{1}{2} = 0.5\ mm$$

$$I = 5\ mm^4$$

C. *Design*

Design 1: Aluminum plate of size 300×60×1 mm without any crack, used as a reference model to study the base material behavior under load.

Design 2: Aluminum plate of same size (300×60×1 mm) with a 45° central crack of 45 mm length, used to analyze stress concentration and deformation effects caused by the crack.

Design 3: Cracked aluminum plate (300×60×1 mm) reinforced with a 1 mm thick epoxy carbon and copper MMC composite patch applied above and below the crack region to evaluate repair efficiency and strength improvement.

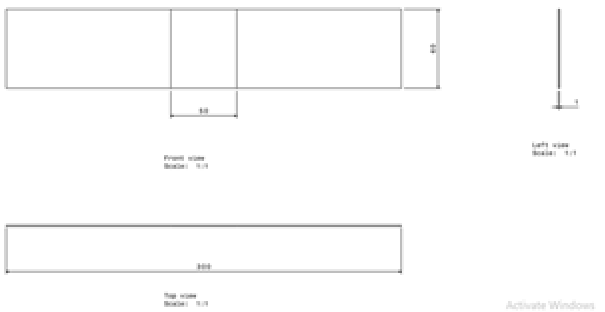

Figure 2. Figure Drafting view of aluminum sheet plate without crack & patch

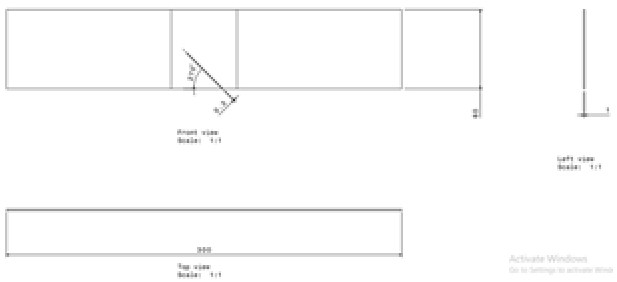

Figure 2. Figure Drafting view of aluminum sheet with crack & without patch

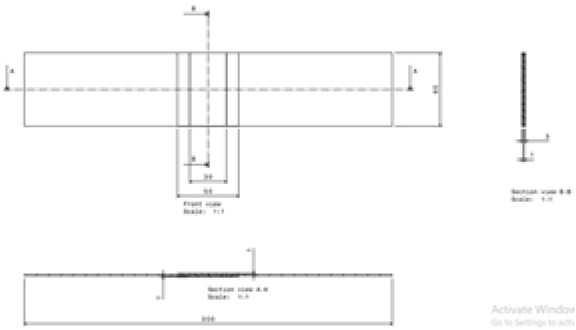

Figure 3. Drafting view of aluminum sheet plate with crack & patch

III. FEA Structural Analysis Results

A. *Boundary conditions*

Tensile Load = 2000 N

One End fixed and another end load.

Mesh Size = 1 mm

Mesh Type = 3D Element Tet-Type

B. *Results Defomration & Stress of all 4 iteration*

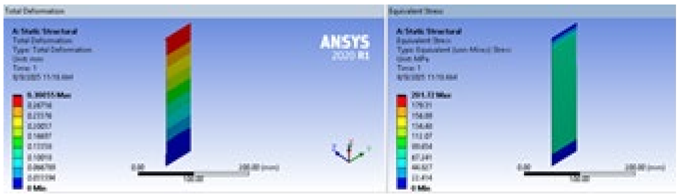

Figure 4. Design 1 Fea Analysis Deformation & Stress Results of aluminum sheet plate without crack & patch

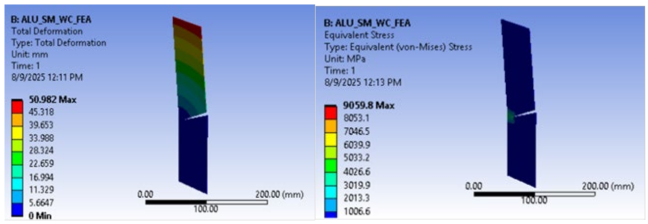

Figure 5. Design 2 Fea Analysis Deformation & Stress Results for aluminum sheet with crack & without patch.

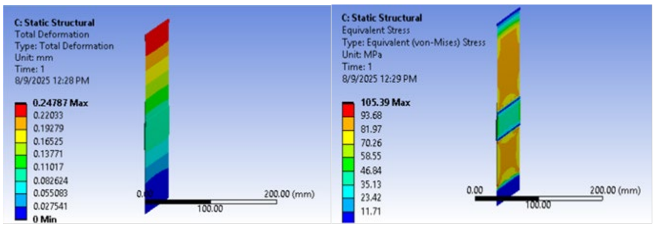

Figure 5. Design 3 Fea Analysis Deformation & Stress Results for aluminum sheet plate with crack & patch with epoxy carbon.

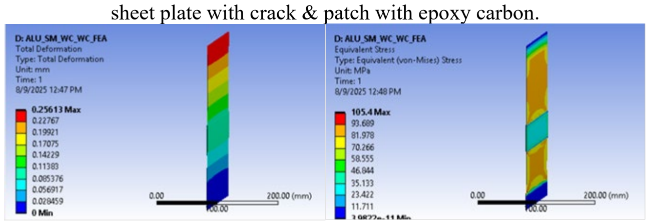

Figure 6. Design 3 Fea Analysis Deformation & Stress Results for aluminum sheet plate with crack & patch with Copper Revit Platted .

C. Conclusion on Results of FEA

The cracked sheet (Iteration 2) catastrophically failed under the 5,000 N load: deformation jumped from 0.3086 mm → 50.982 mm and von-Mises stress from 201.72 MPa → 9,095.8 MPa. This is a very large stress concentration at the crack (clearly a failed/unstable state). Both patch repairs (carbon fiber — Iteration 3, copper rivet — Iteration 4) reduced deformation and stresses dramatically compared with the cracked case: Iteration 3 (fiber): deformation 0.2479 mm (≈ 19.7% lower than uncracked), von-Mises 105.39 MPa (≈ 47.8% lower than uncracked). Iteration 4 (copper rivet): deformation 0.2561 mm (≈ 17.0% lower than uncracked), von-Mises 105.40 MPa (≈ 47.8% lower than uncracked).

In short: the patches not only healed the catastrophic failure, they produced a part that, under static loading, shows lower stress and less deformation than the original intact sheet — because the patch stiffens and redistributes load away from the thin aluminum.

Direct patch comparison (carbon fiber vs copper rivet)

- Von-Mises stress and Sxy shear are essentially the same for both patches (≈ 105 MPa, ~16 MPa respectively).
- Differences appear in shear XZ and overall deformation:
- Carbon fiber: SXZ = 20.57 MPa, deformation 0.2479 mm.
- Copper rivet: SXZ = 28.12 MPa, deformation 0.2561 mm.
- So carbon fiber gives slightly better performance (lower shear XZ and slightly lower deformation) than copper rivets in your model.

IV. EXPERIMENTATION AND CONCLUSION

Step 1 – Material Procurement:

Aluminum sheets of 1 mm thickness are purchased along with carbon fiber roll mats, epoxy resin, softener, and hardener. These materials are selected for their high strength-to-weight ratio and bonding compatibility for composite repair applications.

Step 2 – Cutting of Aluminum Sheet:

The aluminum sheet is cut accurately to the designed dimensions (300 mm × 60 mm) using a shear cutter or CNC machine. Care is taken to maintain smooth edges and avoid surface defects that could affect bonding or testing.

Step 3 – Composite Patch Preparation and Coating:

A 1 mm thick carbon fiber patch is prepared and applied to the damaged area of the aluminum sheet using epoxy resin as the bonding medium. The resin, softener, and hardener are mixed in proper ratios to ensure uniform adhesion. The coated specimen is allowed to cure under room temperature or mild heating conditions to achieve optimal strength.

Step 4 – Mechanical Testing:

The repaired aluminum specimen is tested under tensile loading using a Universal Testing Machine (UTM). Parameters such as ultimate tensile strength, yield strength, and elongation are recorded to evaluate the improvement due to the composite repair.

Step 5 – Validation with Simulation:

The experimental results are compared with the ANSYS Static Structural simulation data. The validation helps confirm the accuracy of the simulation model and assess how closely the analytical and experimental results align in terms of stress, strain, and deformation behavior.

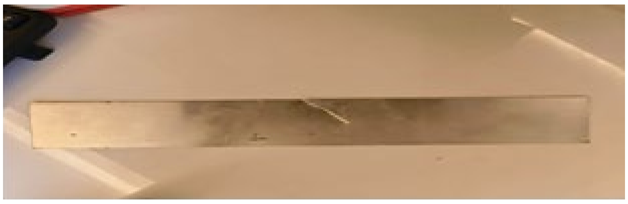

Figure 7. Aluminum Sheet with Crack at center

Sr. No	Type of Iteration	Deformation in mm	Von-Misses Stress in MPa	Shear stress in XY in MPa	Shear stress in YZ in MPa	Shear stress in XZ in MPa
1.	Only Aluminum	0.30855	201.72	28.335	47.432	74.101
2.	Aluminum with crack	50.982	9095.8	1246.8	26.074	486.28
3.	Aluminum with crack & Fiber patch.	0.24787	105.39	15.996	8.8702	20.574
4.	Aluminum with crack & Copper patch	0.25613	105.4	16.0	8.8722	28.1227
5.	Experimental with Epoxy Carbon	0.2479	-	-	-	

Figure 8. Overall Results column

CONCLUSION

The experimental and simulation analyses demonstrate the effectiveness of composite patch repair for cracked aluminum structures. The unreinforced cracked sheet failed catastrophically under a 5000 N load, with deformation surging from 0.3086 mm to 50.982 mm and von Mises stress reaching 9095.8 MPa, indicating severe instability. In contrast, both the carbon fiber (Iteration 3) and copper rivet (Iteration 4) repairs significantly improved load distribution and reduced deformation and stress levels. The carbon fiber patch showed the best performance with 0.2479 mm deformation and 105.39 MPa von Mises stress, compared to 0.2561 mm and 105.40 MPa for the copper rivet patch. This indicates approximately 48% reduction in stress and around 19% lower deformation compared to the uncracked aluminum sheet.

Overall, the carbon fiber–epoxy composite proved to be more efficient, offering better stiffness, reduced shear (SXZ = 20.57 MPa vs 28.12 MPa), and enhanced structural stability. Thus, composite patch repair not only restored the cracked aluminum but also improved its mechanical performance beyond that of the original intact sheet.

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