"Design and Analysis of Aluminium's 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.

Key Words: Aluminium repair, Epoxy carbon composite, Copper MMC, Structural analysis, Finite element method.

1. 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. It also leads to loss of man hours and aircraft availability. Hence it is necessary to repair the damaged aircraft to improve its service life, maintainability, and reliability. Aluminum alloy structures can be repaired by rivets and bolts this requires drilling and increases the chance of corrosion whereas repairing done by adhesively bonded composite patches restores the strength and stiffness of components without these drawbacks.

This technology was first used for the repair of military aircraft and then applied also to civil aircraft. The success of a bonding repair depends on the properties of both the adhesive and the patch. The performance of the adhesive plays a key role in the successful utilization of bonded composite patch repairs. The role of a bonded composite patch is to restore the stress state modified by the presence of the crack. The stress intensity factor is then reduced by the presence of the patch. Many authors have already investigated the behavior of metallic structures repaired by composite patches.

Fiber reinforced polymer (FRP) composite patches are adhesively bonded to a metallic structure as a repair method to either restore the load carrying capacity of a damaged structure or to increase damage tolerance in an undamaged structure as reinforcement. This patch forms a hybrid structure consisting of the metal surface, the composite patch, and an adhesive which bonds the two together. The adhesive transfers loads between metal and composite and provides a stiff connection due to its large area for load transfer, despite its own relatively low stiffness.

2. OBJECTIVE

1. To Identify and characterize the existing cracks in aluminum structures to understand the extent of damage.
2. To validate the effectiveness of the proposed repair solution by comparing simulation results with established manufacturing modal by UTM Testing it.

3. ANALYTICAL CALCULATION & DESIGN

To find the out the mass of the part body

$$M = \rho * L * W * H \text{ in } Kg$$

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

M is mass, ρ is the density (units: mass per unit volume, L = 300 mm, W= 60 mm, H= 1 mm

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

Bending moment formula

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

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

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

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

$$I = 5\ mm^4$$

A. 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.

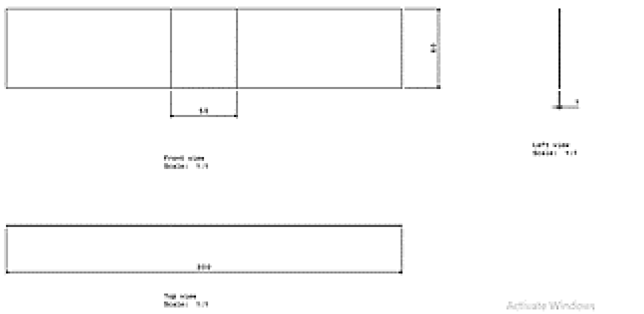


Figure 2. Figure Drafting view of aluminum sheet plate without crack & patch

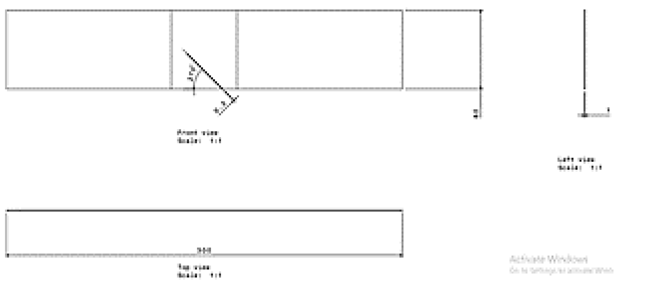


Figure 2. Figure Drafting view of aluminum sheet with crack & without patch

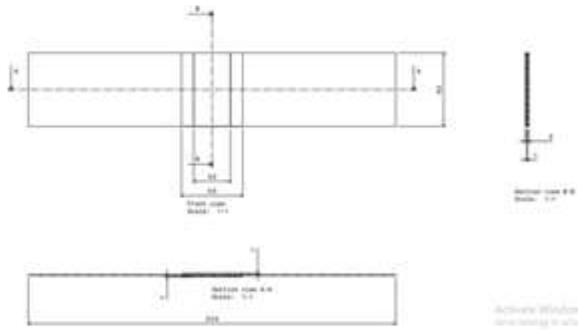


Figure 3. Drafting view of aluminum sheet plate with crack & patch

I. 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 Deformation & Stress of all 4 iteration

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

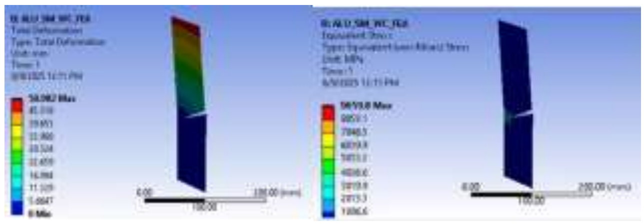


Figure 5. Design 2 Fea Analysis Deformation & Stress Results for aluminum sheet with crack & without patch.

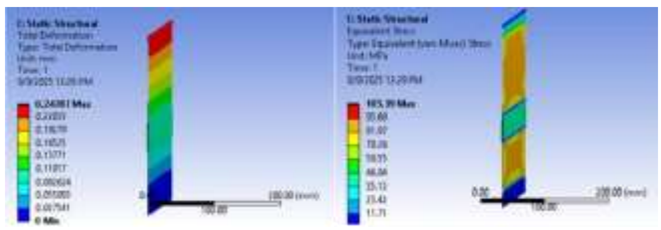


Figure 5. Design 3 Fea Analysis Deformation & Stress Results for aluminum sheet plate with crack & patch with epoxy carbon.

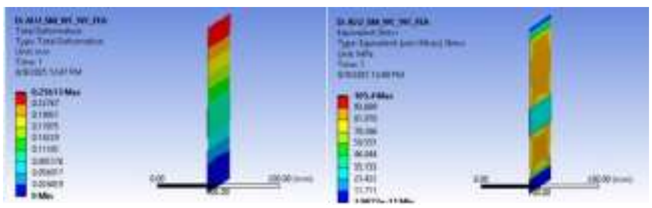


Figure 6. Design 3 Fea Analysis Deformation & Stress Results for aluminum sheet plate with crack & patch with Copper Revit Platted.

4. EXPIRIMENT

Step 1 - Material Procurement: Purchase of Aluminum sheet of thickness 1 mm and carbon fiber roll over mat with epoxy resin softener and hardener.

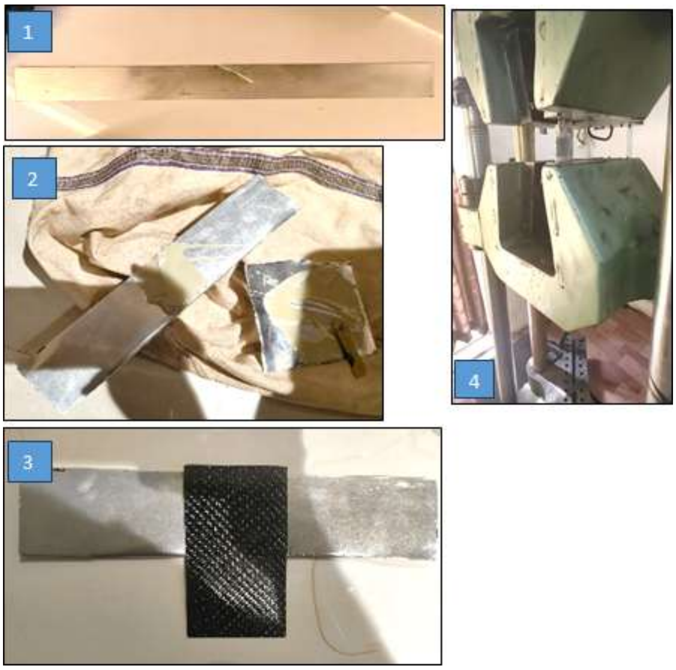
Step 2 – Cutting of Aluminum Sheet: The aluminum sheet is cut accurately to the designed dimensions (300 mm × 60 mm) using a shear cutter or CNC machine. Care is taken to maintain smooth edges and avoid surface defects that could affect bonding or testing.

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: Testing of Part body using UTM Tensile loading condition.

Step 5 – Validation with Simulation.



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	-	-	-	

5. CONCLUSIONS

1. 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).

2. The experimental and simulation analyses demonstrate the effectiveness of the composite patch for cracked aluminum structure. 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 and copper rivet repairs significantly improved load distribution and reduced deformation and stress levels. 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, restored cracked. Aluminum improved its mechanical performance beyond that of the original intact sheet

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