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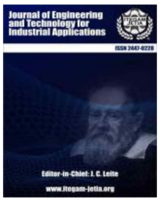

RESEARCH ARTICLE OPEN ACCESS

INVESTIGATION OF FRACTURE BEHAVIOR IN MODE I AND II FOR REPAIRED EDGE-INCLINED CRACKS WITH TRAPEZOIDAL COMPOSITE PATCHES

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ABSTRACT

Numerous studies have shown the effectiveness of composite patch repairs. However, many of these investigations primarily address the enhancement of repaired components' lifespans, focusing mainly on opening mode (Mode I). In real-world applications, cracked components often undergo mixed mode loading that includes both Modes I and II. This article examines the stress intensity factors for Modes I and II in relation to the fracture behavior of a tensile-loaded aluminum plate (Al 7075) featuring a 45° inclined lateral crack repaired on both sides with a unidirectional graphite/epoxy composite trapezoidal patch. A three-dimensional finite element model of the repaired specimen is employed to explore how composite patching affects critical crack tip parameters (KI, KII, and stresses). This approach demonstrates how the properties of the composite and adhesive impact the repaired structure's behavior and the effectiveness of the bonded composite patch. The findings reveal that trapezoidal composite patch can significantly reduce the stress intensity factors KI and KII, thereby extending the service life of cracked structures

I. INTRODUCTION

The composite repair methodology has established itself as an effective and pragmatic solution for repairing cracked structures. This approach involves bonding a composite patch to the damaged areas of the structure, providing multiple benefits: it avoids additional stress concentrations, enhances the stiffness-to-weight ratio, accommodates complex geometries, and enables effective repairs of irregular components. Fiber-reinforced polymers are increasingly preferred over metallic patches due to their superior mechanical properties, as well as their resistance to fatigue and corrosion [1], making them ideal for structural applications. Numerical analysis has become a cornerstone in evaluating composite patch repairs, widely accepted within the research community as a method to assess performance without relying on sophisticated instruments [2]. Critical parameters such as the stress intensity factor (SIF) and the J-integral, alongside interfacial adhesive stresses, are essential for estimating both repair efficiency and durability.

While much of the existing literature has focused on straight cracked panels subjected to Mode I load such as [3-5], real-world applications often involve mixed-mode loading conditions, which present significant practical challenges and opportunities for further investigation [6]. The Finite Element Method (FEM) is a powerful tool for examining structural performance. The Finite Element Method (contour integral) stands out by allowing for the modeling of cracks in a mesh-dependent fashion, facilitating the simulation of crack intensity factors investigation. Notable studies, such as those by [7], have successfully applied XFEM to analyze 3D crack models, while Talebi et al. employed both the cohesive zone model (CZM) and XFEM to simulate adhesive damage and crack growth in structural panels. Other researchers have utilized the Cohesive Zone Modeling (CZM) method to assess failure mechanisms in repair processes, as demonstrated in the studies by [8] and [9], as well as [10]. Who has shown that the stress intensity factor for patched cracks exhibits asymptotic behavior as the crack length increases.

This phenomenon arises because stress is effectively transferred to the patch through the adhesive layer, highlighting the importance of adhesive properties in repair performance. Most studies focus on plates with non-inclined cracks, but this is not always the case in practice [6]. In fact, several studies have emerged in this area, such as the work of [11], who calculated the stress intensity factor in mixed mode for an inclined central crack. These oblique cracks pose additional challenges in terms of diagnosis and repair. Standard techniques developed for orthogonal cracks do not always apply optimally. The influence of the composite's geometric properties on repair effectiveness has been a significant focus in the literature. By [12] used multi-objective optimization design of composite patch repair, while [13] and [14] conducted numerical analyses comparing octagonal, circular, and elliptical patch designs.

Their findings indicate that the shape of the patch plays a crucial role in determining the stress intensity factor at the crack tip. Selecting an appropriate patch shape can significantly lower stress levels at the edges, ultimately enhancing the durability and effectiveness of the repair This paper presents a comprehensive investigation of an inclined cracked panel reinforced with a composite patch using the contour integral method. The study focuses on numerical analysis, using the commercial software Abaqus. The entire assembly is subjected to Mode I and II loading, enabling the determination of the stress intensity factors and interfacial adhesive stresses, to reveal the critical stress zones at this interface for a trapezoidal patch. The patch is installed symmetrically with respect to the plate by means of a thin adhesive layer to cancel out the bending effect due to displacement of the assembly centroid and enhancing the repair effectiveness thereafter.

II. MATERIALS AND METHOD

II.1 GEOMETRIC MODEL

In this study, the repair configuration for edge-inclined cracked plates was modeled using a three-dimensional finite element approach in ABAQUS 2017. To reinforce the crack area, a trapezoidal double-sided patch made of eight layers of Graphite/Epoxy composite was bonded to both surfaces of a Aluminum 7075 alloy plate. The patch was secured with a 0.2 mm layer of Masterbond (EP42HT-3AO) adhesive epoxy, known for its high mechanical strength and excellent resistance to both shear and tensile stresses.

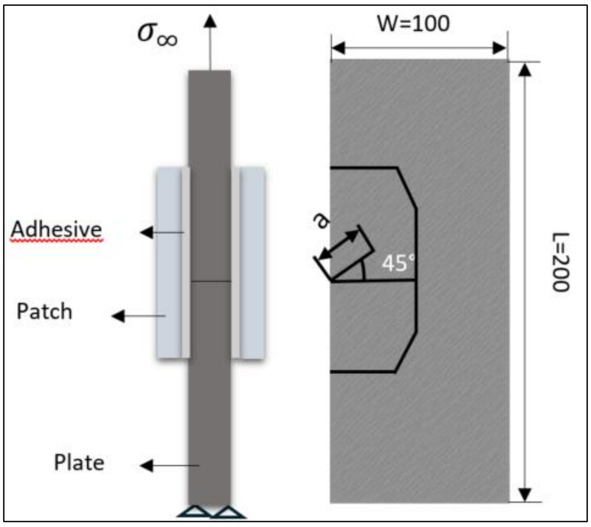


Figure 1: Composite patch repair configuration.
Source: Authors, (2026).

To thoroughly assess the interactions at both the adhesive-plate and adhesive-patch interfaces, a detailed numerical analysis is essential. This interface was modeled in Abaqus using the CZM approach with the BID method. Comprehensive geometrical and mechanical properties for the entire system are provided in Figure 1 and Table 1.Recognizing the importance of adhesive integrity, this study focuses on estimating the service life of repaired structures by closely examining the interaction between the adhesive layer and the composite patch. By analyzing a range of loading conditions and environmental factors, this research aims to predict the durability and reliability of the repair over time.

II.2 MESH MODE

The double-sided configuration utilized in this bonded repair model consists of three materials with varying stiffness. The Bilinear Delamination Interface (BID) approach was employed in the Cohesive Zone Model (CZM) method for modeling the contact zones between patch-adhesive and plate-adhesive. In this model, cohesive elements are used to simulate the joints, and their behavior is governed by a tensile-separation law. To ensure precise simulation, the entire model was meshed using the quadratic meshing method available in ABAQUS 2017 software. This approach enhances the accuracy of the interface behavior analysis and improves the overall fidelity of the numerical model.

Results detailing the rate of reduction of the stress intensity factor KI, KII and the stress distribution for adhesive and composite patch, exactly to highlight the phenomena at the edges of these parts, were obtained from a structural static analysis. An element with a length of 2 mm was designed to create an automatic mesh for the entire assembly of the double-sided repair. A refined mesh was generated at the crack edge using elements with a length of 0.02 mm. The entire model was meshed with 10,692 elements for the substrate, 2,696 elements for the adhesive, and 2,816 elements for the composite. The sizes of these elements were determined following a convergence study.

Table 1: Materials and geometrical proprieties.

Materials	**Aluminum alloy**			**Graphite/Epoxy Composite**		**Epoxy/Resin**	
Geometrical proprieties (mm)	W	L	t	R	t	R	t
	100	200	3	50	1.6	50	0.2
Longitudinal young modulus E_{xy} (GPa)	70			110		3.8	
Transversal young modulus E_{yz} (GPa)	-			7.9		-	
Transversal young modulus E_{xz} (GPa)	-			7.9		-	
Longitudinal Poisson ratio ϑ_{xy}	0.33			0.34		0.4	
Transversal Poisson ratio ϑ_{yz}	-			0.35		-	
Transversal Poisson ratio ϑ_{xz}	-			0.5		-	
Longitudinal shear modulus G_{xy} (GPa)	27			4		0.5	
Transversal l shear modulus G_{yz} (GPa)	-			2.75		-	
Transversal shear modulus G_{xz} (GPa)	-			2.7		-	

Source: Authors, (2026).

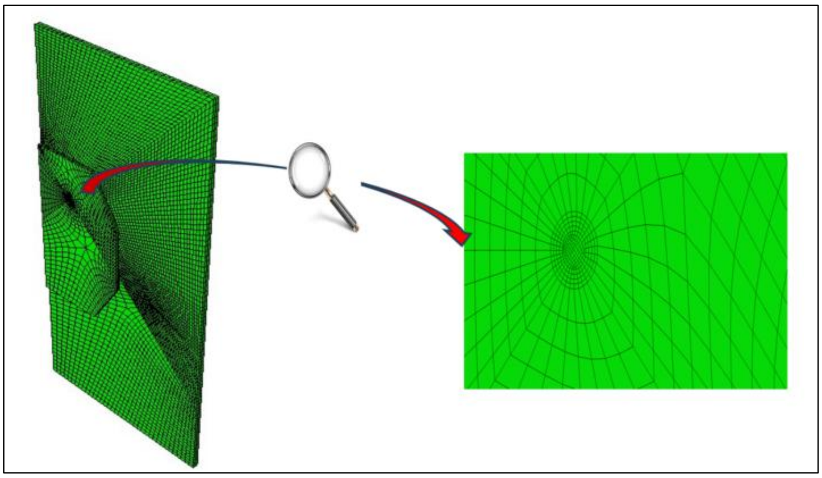


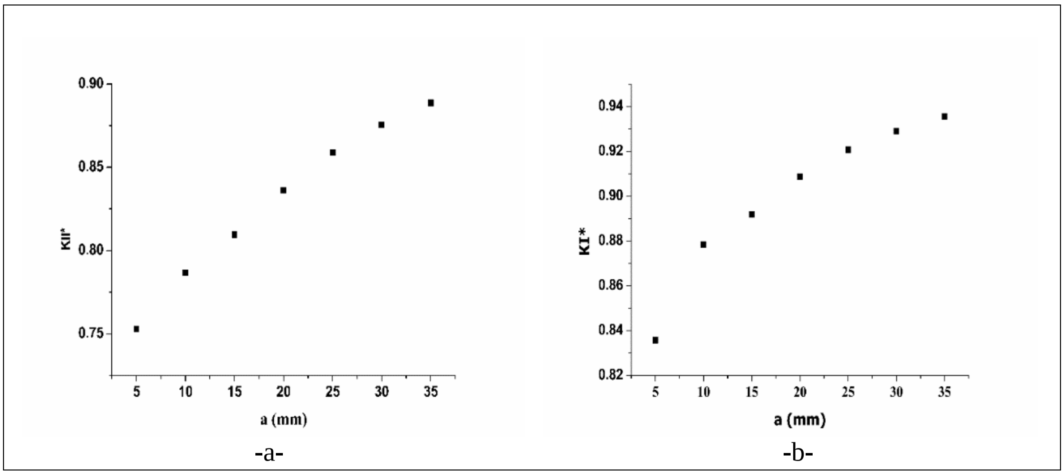
Figure 2: Finite-element mesh.
Source: Authors, (2026).

III. MATERIALS AND METHODS

Write in detail the research project, including background and limitations. The selection of materials and methods, procedures and equipment must be justified so that the work can be reproduced. Modifications or new methods must be described in detail. You must clearly define the universe and specify how the sample was selected and why it is representative. Data processing represents the practical development of a theoretical basis, deriving the model equations to program the calculation algorithm, according to the need. In materials, they include the technical specifications and the quantities, the origin and, if necessary, the method for its elaboration.

IV. RESULTS AND DISCUSSIONS

Figures 3.a and 3.b respectively represent the reduction rate of the stress intensity factor in mode I and mode II as defined by equation (1):



-a- -b-

Figure 3: Rate of stress intensity factor restitution.
Source: Authors, (2026).

$$KI^{*} = 1 - {KI^{p}}/{KI^{unp}} \quad (1)$$

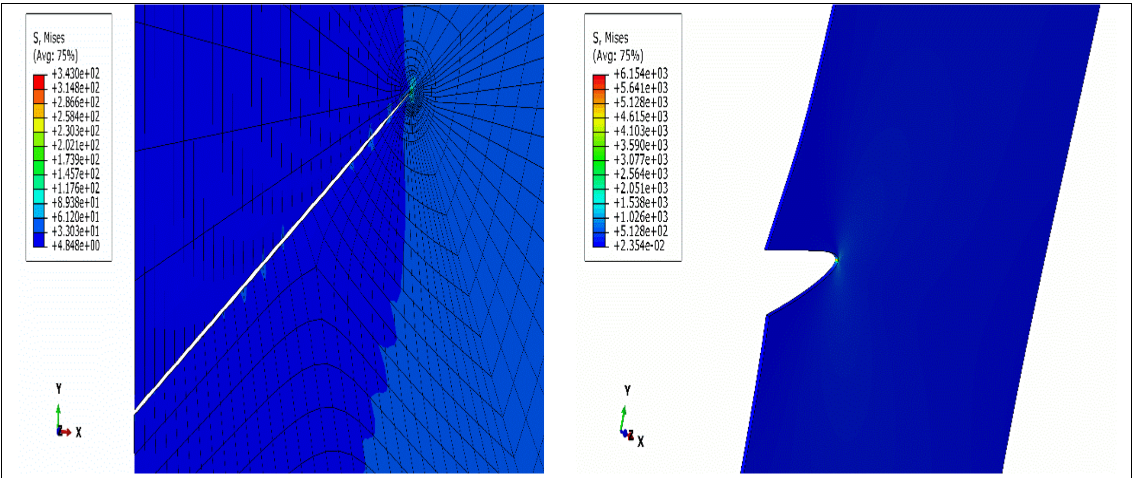
Where:

KI^{*}: is the rate of reduction in stress intensity factor.

KI^{p}: is the stress intensity factor for patched plate.

KI^{unp}: is the stress intensity factor for unpatched plate.

In Graph 3-a, we observe a significant reduction in the stress intensity factor, particularly for large cracks, where the stress intensity factor for a plate without a composite patch is considerably higher compared to a plate with a patch. This indicates a near-stability of the stress factor for a structure reinforced with a composite patch. This is also true for the stress intensity factor in mode II, as seen in Graph 3-b, with a significantly greater difference in mode I due to the low inclination angle (45°) favoring mode I opening.



-a- -b-

Figure 4: Von mises stress for the plate.
Source: Authors, (2026).

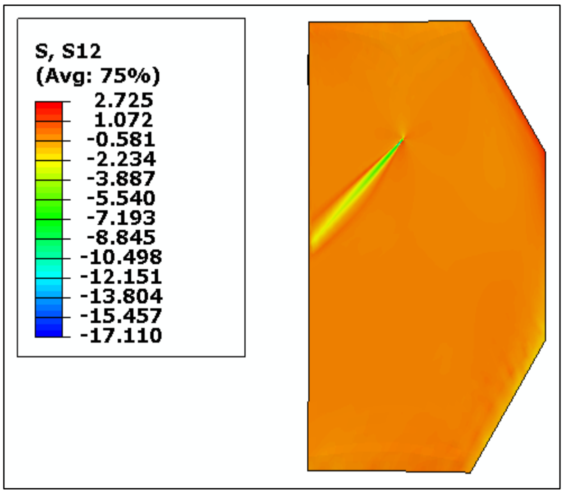


Figure 5: Shear stress S_{xy}.
Source: Authors, (2026).

In Figure 4, which illustrates the von Mises stress distribution, 'a' corresponds to a reinforced plate, while 'b' shows a non-reinforced plate. It is evident that the risk of structural failure in the aluminum plate is significantly reduced with reinforcement. The stress concentration is much lower in the reinforced plate, indicating that the structure-patch-adhesive system effectively mitigates the potential for cracking. This suggests that the failure mechanism of the entire assembly is unlikely to be linked to the failure of the plate itself, highlighting the effectiveness of the reinforcement in enhancing structural integrity.

The three figures 5, 6 and 7 provide insights into the shear stress distribution across the xy, xz, and yz planes at the interface of a laterally inclined, cracked aluminum plate that has been reinforced with a bonded trapezoidal graphite composite patch.The main areas of focus in this analysis are the behavior of the shear stress at the edges and the region around the crack, especially considering the tensile load applied in the y-direction. In Figure 5, which depicts the shear stress in the xy plane (S_{xy}). It is observed that the shear stress is in the xy plane shows an increase near the edges. This elevated stress is likely due to both the boundary conditions applied to the plate and the localized influence of the bonded composite patch, which modifies the stress field at the interface.

Higher shear stress values at the edges can create localized stress concentrations, potentially impacting the durability and structural integrity of the bond between the aluminum plate and the composite patch. and around the crack region, the stress distribution is influenced by the combination of the patch geometry and the crack inclination. The trapezoidal patch may redistribute shear stress along the crack line, reducing stress intensity at certain points while potentially creating localized peaks that could affect crack propagation. The composite patch likely absorbs some of the shear stress, helping to relieve stress directly on the crack tips.

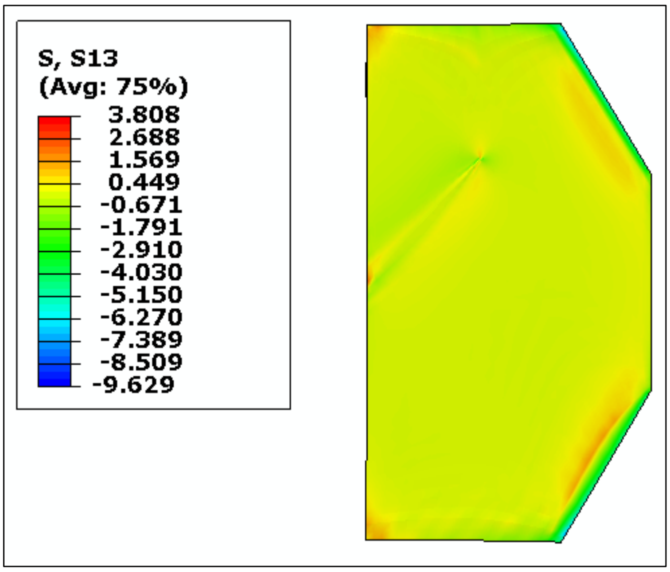


Figure 6: Shear stress S_{xz}.
Source: Authors, (2026).

In the xz plane, as shown in figure 6. The edges also exhibit stress gradients, although these may vary in intensity compared to the xy plane. This difference is due to the composite patch's layered structure and the properties of the adhesive, which contribute to unique shear stress behavior at the interface in this plane. And near the crack, the xz plane gives insight into how the composite patch and adhesive layer interact with the plate under loading. Here, the patch likely helps in redistributing stress away from the crack tip, reducing the tendency for crack propagation in this plane and allowing the adhesive to contribute effectively to stress absorption.

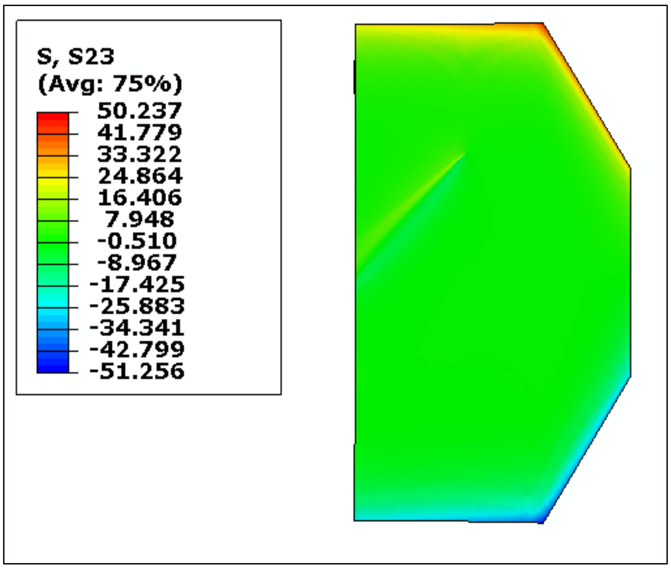


Figure 7: Shear stress S_{yz}.
Source: Authors, (2026).

Due to the tensile load applied in the y -direction, the figure 7 shows higher overall shear stress in yz plane, compared to the xy and xz planes. This load increases the shear stress particularly along the bonded edges, emphasizing the role of the adhesive in maintaining bond strength and preventing shear-induced separation. In the yz plane, the tensile loading causes a direct increase in shear stress intensity around the crack. This stress amplification aligns with the crack direction and contributes to higher shear stress near the crack tips. The composite patch's trapezoidal shape plays a significant role here, working to redistribute some of this stress away from the crack tip while maintaining the bond along the interface.

This analysis highlights the importance of considering both the material properties and the load direction, as they play a critical role in the distribution of stress around the crack and at the edges. The bonded patch is instrumental in managing stress intensity around the crack, although the adhesive strength and patch geometry must be sufficient to handle these concentrated stresses, especially on the xy plane under tensile loading.

V. CONCLUSIONS

The results above highlight the effectiveness of bonded patch repair in enhancing the structural integrity of aluminum plates. Figure 3 shows a significant reduction in stress intensity factors for both Mode I and Mode II, demonstrating the stabilizing effect of the composite patch. Figures 4-a and 4-b further emphasize the reduction in von Mises stress in reinforced plates compared to non-reinforced ones, confirming the patch’s role in lowering the risk of structural failure. However, Figures 5, 6, and 7 reveal that, while the patch effectively distributes stress, the adhesive layer remains a critical point of concern due to elevated shear stress concentrations, particularly at the edges and near cracks. This suggests that, although bonded patch repair significantly improves the durability and lifespan of the structure, careful attention must be given to the adhesive layer to prevent debonding and ensure the long-term effectiveness of the repair. Overall, bonded patch repair proves to be a robust method for extending the service life of damaged structures, provided that the adhesive integrity is maintained.

VI. AUTHOR’S CONTRIBUTION

Conceptualization: Achour Toufik, Chaour Mohamed, Boucherma Djamel, Boulkroune Sofiane and Hamadi Billel.
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Investigation: Achour Toufik, Chaour Mohamed and Hamadi Billel.
Discussion of results: Achour Toufik, Boulkroune Sofiane and Hamadi Billel.
Writing – Original Draft: Achour Toufik, Cherrad Mohamed Lotfi and Chaour Mohamed.
Writing – Review and Editing: Achour Toufik, Cherrad Mohamed Lotfi, Boucherma Djamel, Boulkroune Sofiane and Hamadi Billel.
Resources: Achour Toufik, Cherrad Mohamed Lotfi and Chaour Mohamed.
Supervision: Achour Toufik, Cherrad Mohamed Lotfi, Chaour Mohamed, Boucherma Djamel, Boulkroune Sofiane and Hamadi Billel.
Approval of the final text: Achour Toufik, Cherrad Mohamed Lotfi, Boulkroune Sofiane and Hamadi Billel.

VII. REFERENCES

[1] F. Benyahia, A. Albedah, and B. B. Bouiadjra, "Analysis of the adhesive damage for different patch shapes in bonded composite repair of aircraft structures," Materials & Design (1980-2015), vol. 54, pp. 18-24, 2014.

[2] A. H. Makwana, N. Vyas, and R. Barot, "Numerical investigation of composite patch repair of inclined cracked panel using XFEM," Materials Today: Proceedings, vol. 45, pp. 5128-5133, 2021.

[3] N. Azzeddine, A. Benkheira, S. M. Fekih, and M. Belhouari, "Numerical study of bonded composite patch repair in damaged laminate composites," Advances in aircraft and spacecraft science, vol. 7, no. 2, pp. 151-168, 2020.

[4] F. Benyahia, L. Aminallah, A. Albedah, B. B. Bouiadjra, and T. Achour, "Experimental and numerical analysis of bonded composite patch repair in aluminum alloy 7075 T6," Materials & Design, vol. 73, pp. 67-73, 2015.

[5] S. Chorfi, B. Hamadi, and T. Achour, "Vibration of orthotropic plates with and without damping," studies in engineering and exact sciences, vol. 5, no. 2, p. e9982, 10/31 2024, doi: 10.54021/seesv5n2-421.

[6] W. Oudad, D. E. Belhadri, H. Fekirini, and M. Khodja, "Analysis of the plastic zone under mixed mode fracture in bonded composite repair of aircraft structures," Aerospace Science and Technology, vol. 69, pp. 404-411, 2017.

[7] B. Heng, "Damage Analysis of Aluminum Structure Repaired with a Composite Patch," 2018.

[8] M. A. Bellali, B. Serier, M. Mokhtari, R. D. Campilho, F. Lebon, and H. Fekirini, "XFEM and CZM modeling to predict the repair damage by composite patch of aircraft structures: Debonding parameters," Composite Structures, vol. 266, p. 113805, 2021.

[9] R. Rocha and R. Campilho, "Evaluation of different modelling conditions in the cohesive zone analysis of single-lap bonded joints," The Journal of Adhesion, vol. 94, no. 7, pp. 562-582, 2018.

[10] M. De Moura, "Application of cohesive zone modeling to composite bonded repairs," The Journal of Adhesion, vol. 91, no. 1-2, pp. 71-94, 2015.

[11] M. Ayatollahi and R. Hashemi, "Mixed mode fracture in an inclined center crack repaired by composite patching," Composite Structures, vol. 81, no. 2, pp. 264-273, 2007.

[12] Y. Zhao, S. Xuan, Y. Wang, Y. Li, and X. Yao, "Reliability-based multi-objective optimization design of composite patch repair structure using artificial neural networks," Composite Structures, vol. 352, p. 118692, 2025/01/15/ 2025, doi: 10.1016/j.compstruct.2024.118692.

[13] M. Belhouari, B. B. Bouiadjra, A. Megueni, and K. Kaddouri, "Comparison of double and single bonded repairs to symmetric composite structures: a numerical analysis," Composite Structures, vol. 65, no. 1, pp. 47-53, 2004.

[14] D. Ouinas, B. B. Bouiadjra, B. Achour, and N. Benderdouche, "Modelling of a cracked aluminium plate repaired with composite octagonal patch in mode I and mixed mode," Materials & Design, vol. 30, no. 3, pp. 590-595, 2009.