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# Evaluating the Repair Performance of the Cracked Plate Using Adhesive Shear Stresses

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## Abstract

The aim of this study is to investigate the repair performance a cracked aluminum plate repaired with aluminum patch by using the effects of the crack length on adhesive shear stresses. Cracked aluminum plate was repaired using the aluminum patch and the adhesive Araldite 2015. It is known that shear stresses developed in bonded structures are critical ones. Distributions of the adhesive shear stresses along the adhesive layer were obtained using Franc 2D/L software. It was concluded that shear stress $\tau_{zx}$ along the longitudinal direction becomes peak at the crack tip. However, it was seen that shear stress $\tau_{zy}$ along the transverse direction is maximum at the ends of the adhesive bondline.

**Key words:** Adhesive shear stress, finite element method, repair performance

## 1. Introduction

The use of adhesives has become widespread due to their superiority over other applications. It is known that aircraft structures have been generally repaired with riveted patches (See Fig. 1). Similar to known classical methods, bonded repair procedure has also lots of factors which effect to the repair efficiency, such as the thickness and material type of the adhesives and patch materials. The shear stresses developed in bonded cracked-structures have been studied in a limited number of papers in the open literature. Bouiadjra et al. [2] made a comparison between the carbon-epoxy and aluminum patch for repairing aircraft structures. They showed that the structure repaired with composite patch caused more adhesive shear stress than the structure repaired with aluminum patch. They also compared the stress intensity factor variations with respect to using composite and aluminum patch structures in the joint. In addition, they also studied the effect of patch type for life cycle of repaired cracked-structure. Benyahia et al. [3] analyzed the effect of the geometrical shapes of the composite patches on the repair performance of the joint. They concluded that the elliptical patch is the optimal one for the repairing, due to this type of patch gave somewhat lower values for the SIFs at crack tip. Fekih et al. [4] tried to optimize the sizes of composite patches for repairing aircraft structures. They obtained that the patch dimensions have an influence upon mechanical strength of the assembly. Additionally, they concluded that the increasing in the patch dimensions reduces the J integral values at crack tip. Bezzerrouki et al. [5] made a comparison between double-patch mono-adhesive model and single-patch hybrid-adhesive model for repairing cracked-structures. They concluded that, even if the optimization of the repair parameters for single-patch hybrid adhesive model gives successful results, both of repair configurations have their advantages and disadvantages. Bouiadjra et al. [6]

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studied the fracture energy variations by using composite patch having two adhesive bands. They showed that the fracture energy at the crack tip is highly affected by shear modulus of adhesive used. They concluded that repairing configuration including two-different adhesive bands is an effective way for reducing the shear stress developed especially at the ends of bond length.

In this study a cracked aluminum plate was repaired by an aluminum patch material. To bond the patch and the cracked plate, the adhesive Araldite 2015 was used as an adhesive material. The crack length was taken as variable and assumed to vary as 10, 20, 30, 40 and 50 mm. Finite element analyses were performed with Franc 2D/L software and the distributions of the adhesive shear stresses ($\tau_{zx}$ and $\tau_{zy}$) were obtained and compared each other.

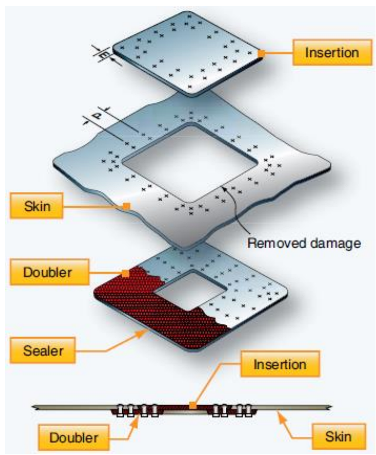


**Figure 1.** Example for a classical repairing process [1]

## 2. Materials and Method

In this study, geometry and dimensions of the joint and patch was taken from the literature [6]. Mechanical properties of the adhesive material Araldite 2015 is given in Table 1.

**Table 1.** Mechanical properties of the adhesive [7]

| | E (MPa) | υ | $G_a$ (MPa) |
|---|---|---|---|
| Araldite 2015 | 1850 | 0.33 | 695 |

*(E: Elasticity modulus, υ: Poisson's ratio, Ga=Shear modulus)*

### *2.1 Geometry and Boundary Conditions*

Due to the symmetry, the half of the geometrical model was used. Dimensions and geometry of the joint are shown in Fig. 2. Height and width of the aluminum plate are assumed to be equal

($H_p$=$w_p$=254 mm). Plate thickness $t_p$ and patch thickness $t_r$ are 3 mm and 2 mm, respectively. Subscript 'r' refers to repair and 'p' denotes plate. The adhesive thickness $t_a$ is constant and assumed to be 0.8 mm. Similarly, height and width of the aluminum patch is equal value ($H_r$=$w_r$=127 mm). Elasticity modulus and Poisson's ratio of the aluminum adherend are $E_p$=72 GPa and ν=0.33, respectively. In Fig. 2, 'a' corresponds to crack length. An initial crack was assumed to be 10 mm and propagated from 10 mm to 50 mm with an increment of 10 mm. The aluminum adherend is subjected to uniaxial tensile stress of σ=70 MPa.

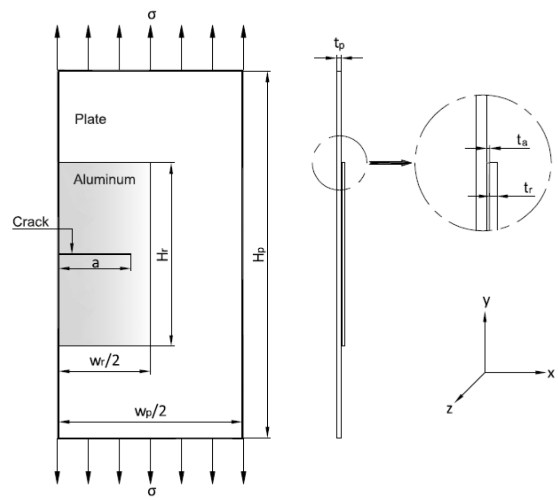


**Figure 2.** Geometry and dimensions of the single lap joint

Half-symmetry boundary condition was used to reduce the solution times (See Fig. 3).

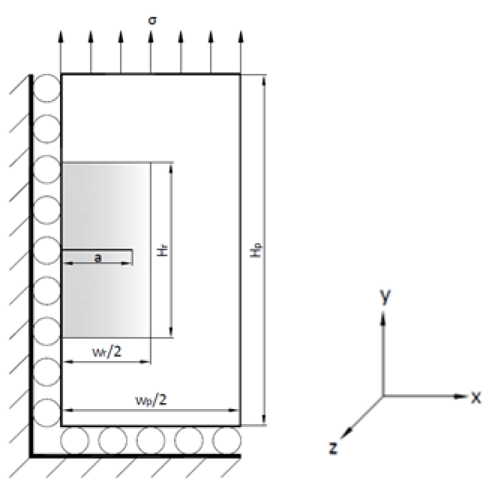


**Figure 3.** Boundary conditions of the single lap joint

### *2.2 Finite Element Method*

In this study, Franc 2D/L finite element software was used for performing the stress analyses and propagating the crack in the structure. Plate and patch were individually meshed using eight nodded-isoparametric elements with quadratic shape functions. These elements have some advantages that the stress singularity at the crack tip can be incorporated in the solution by moving the eight nodes to the quarter-point locations [6]. Mesh scheme is shown in Fig. 4.

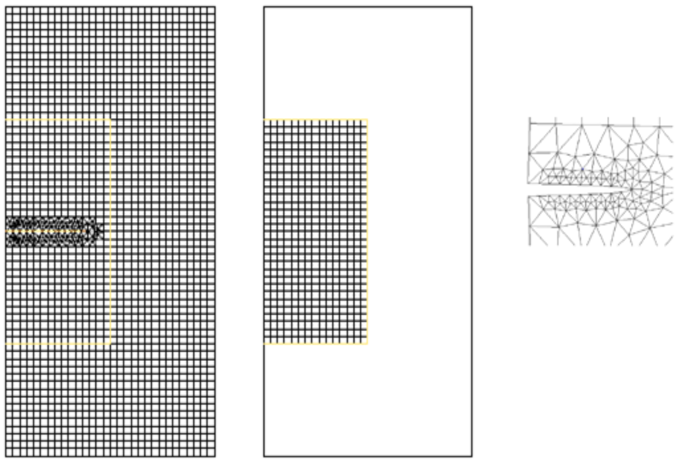

**Figure 4.** Mesh model of the plate, patch and near the crack tip

Franc 2D/L is a software which is able to define adhesive layers between plate and patch. A virtual line perpendicular to crack tip was defined to be used in obtaining the stress distributions. The adhesive shear stresses of $\tau_{zx}$ and $\tau_{zy}$ were then obtained along this virtual line. The virtual line tangent to the crack tip and its schematic represantation is shown in Fig. 5.

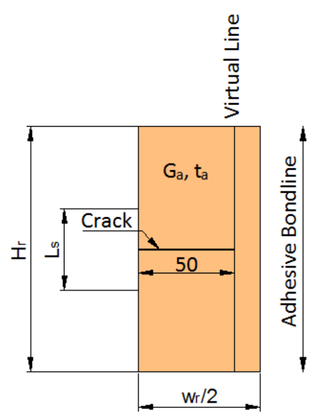


**Figure 5.** Virtual line for mono adhesive model stress distribution

## 3. Results

In this study, repair performance of the joint was studied in terms of the distributions of the adhesive shear stresses ($\tau_{zx}$ and $\tau_{zy}$) along a virtual line perpendicular to crack tip. First analysis was executed for the adhesive shear stress $\tau_{zx}$ along the x-axis direction. The distributions of the adhesive shear stress $\tau_{zx}$ were shown in Fig. 6.

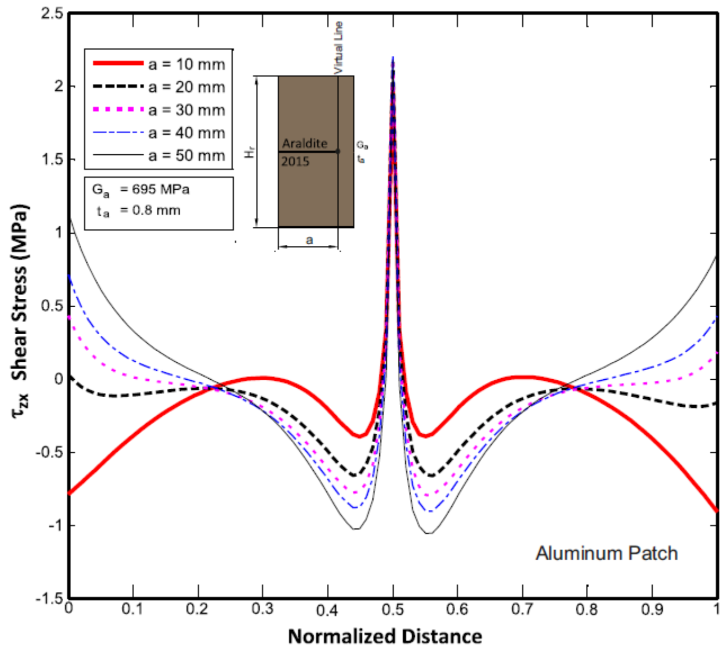


**Figure 6.** $\tau_{zx}$ shear stress distribution for aluminum patch model

It is seen from Fig. 6 that the $\tau_{zx}$ shear stresses reach their peak value at crack tip with the value of 2.21 MPa. It was seen that, for crack lengths 10, 20, 30, 40 and 50 mm, stresses at the ends of the bond length were varied as -0.8, 0, 0.44, 0.72 and 1.15 MPa, respectively.

Secondly, the analysis was performed for the $\tau_{zy}$ adhesive shear stresses along the y-axis direction. The distribution of the shear stress $\tau_{zy}$ can be seen from Fig. 7. It can be seen from Fig. 7 the $\tau_{zy}$ shear stresses reach their maximum value at the ends of the bondline with the value of 8.6 MPa. At the crack tip the $\tau_{zy}$ shear stresses have a value of approximately 2 MPa.

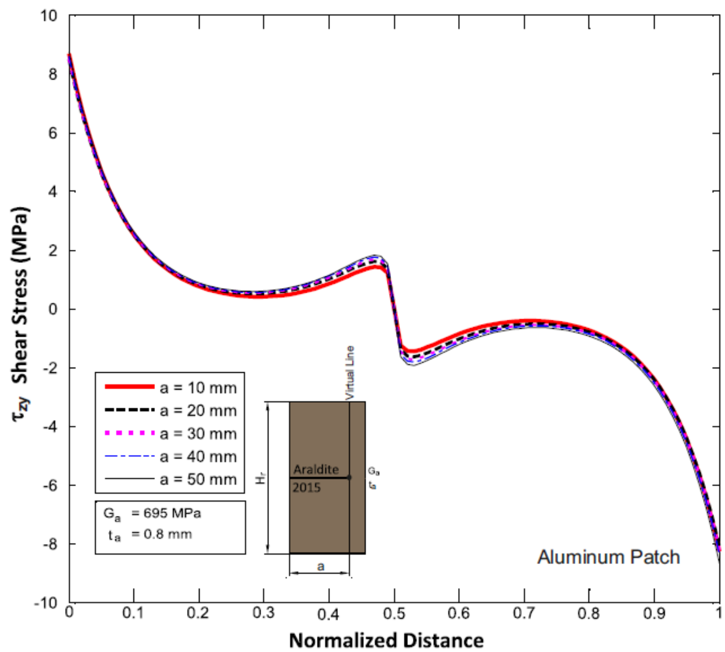


**Figure 7.** $\tau_{zy}$ shear stress distribution for aluminum patch model

## 4. Discussion

Due to the Fig. 6 it can be concluded that increasing in crack length causes an increase in the $\tau_{zx}$ shear stresses at the ends of the bond length. However propagating the crack length has no significant effect for the $\tau_{zx}$ shear stresses at the crack tip. It is clearly seen from Fig. 7 that varying of the crack length has no significant effect on the $\tau_{zy}$ shear stresses and the differences are negligible. It can be seen both of the $\tau_{zx}$ and $\tau_{zy}$ shear stress distributions maximum adhesive shear stress occurs at $\tau_{zy}$ shear stress component. A summary of the adhesive shear stresses can be seen at Table 2 for the crack length 50 mm.

**Table 2.** Critical shear stress components for 50 mm crack length

| | Crack Tip | Bondline End |
|---|---|---|
| $\tau_{zx}$ (MPa) | 2.21 | 1.15 |
| $\tau_{zy}$ (MPa) | 2 | 8.6 |

## Conclusions

In this study, the repair performance a cracked aluminum plate repaired with aluminum patch was studied by investigating the effects of the crack length on adhesive shear stresses. It is concluded that $\tau_{zx}$ adhesive shear stresses is highly affected at the ends of the bond length by the size of the crack length. Maximum values of the $\tau_{zx}$ shear stresses developed at the crack tip and the differences between stress values which change with crack length are negligible at crack tip. The results of the $\tau_{zy}$ shear stress analysis shows that crack length has no effect on this stress component. Peak values of $\tau_{zy}$ shear stresses occur at the ends of the bond length. According to the $\tau_{zx}$ and $\tau_{zy}$ stress distributions it can be said that critical peak stresses occur at the ends of bond length. It was concluded that, in order to improve the effectiveness of the repair performance, adhesive shear stresses should be reduced at the ends of the adhesive bond length.

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