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Numerical analysis of the effect of the adhesive shear modulus on a corroded, cracked and repaired plate in mixed mode

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ABSTRACT

The objective of this work concerns a numerical analysis by the three-dimensional finite element method, of the repair by simple composite patch of corroded and cracked Al 2024- T3 plates with a crack inclined to the horizontal at an angle θ=30°. The effect of the adhesive shear modulus on the damaged area and on the D_R damaged area ratio was considered. Then the effect of this parameter on the values of the D_R and the J integral. The results obtained show the rectangular shape is the best because it makes it possible to obtain the lowest values of the J integral. In addition, it is best to use the elliptical shape after analyzing the results for the damaged area (D_R) ratio.

1 Introduction

The protection of aluminum alloys against corrosion is a topic widely studied to date. The works dedicated to this subject are numerous [1-5] and exhaustive. Generalized corrosion, for example, develops in acidic or alkaline environments. It is characterized by an almost uniform decrease in the thickness of the metal, due to the dissolution of the protective film of alumina on the surface of the metal. The resistance of aluminum to generalized corrosion is in fact conditioned by the evolution of this oxide film, in particular its porosity and its hydration [6].

The determination of the SIF at the crack tip is one of the means for analyzing the performance of the bonded patch repair in repairing cracks. This technique was used by several authors [7-10]. Most of the previous works in this domain were limited to the case of mode I crack opening. The finite element method is used with a great accuracy to evaluate the SIF at the crack tip.

Chang-Su Ban et al [11] introduced modifications on the model of the damage zone .The ratio of the damaged area has been suggested for the prediction of the breaking load of the glue joint. For the epoxy adhesive (FM 73), it has been shown that the ratio of the damaged area corresponding to the failure of this adhesive is 0.247.

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Xiaoyan Liu et al [12] studied bonded repair optimization of cracked aluminum alloy plate by microwave cured carbon-aramid fiber/epoxy sandwich composite patch, it can be found that the bending performance of carbon-aramid fiber sandwich composite patches was effectively improved after incorporation of flexible aramid fiber layers into the carbon fiber layers, but the tensile strength of sandwich composite patches was weakened to some extent. Especially, the sandwich patches with 3 fiber layers exhibited better tensile and bending performance in comparison to patches of 5 and 7 fiber layers. The optimized 3-layer carbon-aramid fiber sandwich patch repaired plate recovered 86% and 190% of the tensile and bending performance in comparison to the uncracked ones, respectively, showing a considerable repair majorization effect for the cracked aluminum alloy plate.

Mr. Berrahou Mohamed [13-19] analyzed the effect of the simple patch repair of a corroded plate with a single crack and a structure having two cracks located to the right and left of the corrosion. He concluded that the repair of the structure with double cracking is more balanced as it gives a homogeneous stress distribution at the surface of the repaired part, which leads to the crack growth in regular and predictable. In the study of the damaged area, the circular shape is considered the best shape because it gives us low values of D_R.

The present study was conducted in order to analyze the behavior of a corroded cracked structure with an inclined crack and repaired by simple composite patch. The effect of the adhesive shear modulus was demonstrated on repair quality. We consider an Al 2024-T3 plate having a corrosion of random shape with a crack emanating from length (a) inclined (in mixed mode). The mechanical properties of the plate, the patch as well as the adhesive are shown in Table.1. The influence of the adhesive shear modulus is demonstrated on the variations of the breaking energy and the extent of the adhesive damaged area. Then a comparison of the effect of the geometric shapes of the patch on variations of the values of the integral J and those of the adhesive damaged area ratio (D_R).

2 Geometric model.

The geometry of the structure considered in this study is illustrated in figure 1. A thin plate aluminum elastic Al 2024-T3 with the following dimensions: (height H_{Pl} = 254 mm, width W_{Pl} = 254 mm and thickness e_{Pl} = 5mm) with corrosion of random shape. The plate was repaired with a simple patch carbon-epoxy thickness e_p = 1.5mm, the folds in the patch are unidirectional where the fibers are oriented along the length direction of the specimen (parallel to the load direction). The elastic properties of the different materials are given in table .1[13].

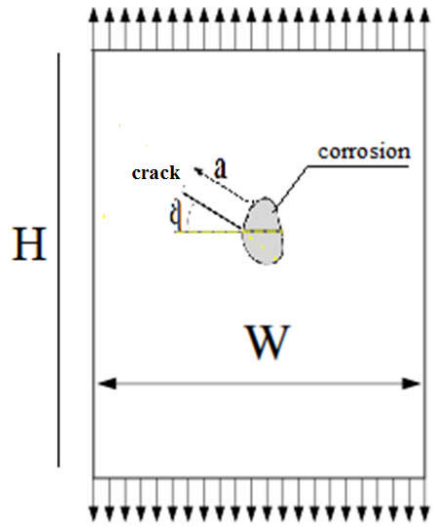

Fig. 1 Geometric model of the corroded cracked plate, repaired by rectangular patch

In order to analyse the effect of the patch shape, four shapes were chosen in this study: rectangular, trapezoidal, circular and elliptic. The shapes and dimensions of these patches are shown in fig. 2. The patch is glued to the plate with the adhesive FM-73 of thickness ea= 0.15 mm. The plate is subjected to a uniaxial tensile load of amplitude σ=200MPa.

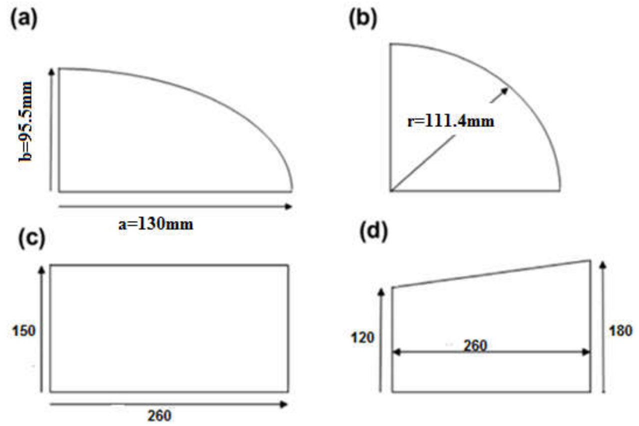

Fig. 2 Dimensions of the patches (a) elliptical, (b) circular, (c) rectangular and (d) trapezoidal

Table 1-Elastic properties of different materials [13]

Mechanical properties	Aluminium 2024-T3	Carbone/epoxy	(FM73)
Longitudinal Young Modulus E_1(GPa)	72	210	4.2
Transversal Young Modulus E_2(GPa)		19.6	
Shear Modulus G_r(GPa)		5.460	
Longitudinal Poisson Coefficient ϑ_{12}	0.33	0.3	0.32
Transversal Poisson Coefficient ϑ_{13}		0.2	

The finite element analysis of the configuration shown in Figure 3 was performed using the ABAQUS code [20]. The shape of the mesh of the structure around the corrosion can be identified in this figure. A regular mesh is carried out for all the structure. This mesh remains the same throughout the calculation in order to avoid any influence of the mesh on the results. The perfect bond is created between the plate and the composite patch by merging the nodes of the elements. The fact of merging the nodes results in having the same mesh for the structure and for the composite patch. The corrosion and crack are located almost in the middle of the plate causing a stress concentration. Therefore, a refined mesh is made around the inclined crack and also around the corrosion. The total number of elements of the structure is equal to 50,000. The size of the side of an element away from the crack is equal to 0.015 mm for the whole structure and 0.001 mm in the vicinity of the crack. The finite element model consisted of three subsections to model the cracked plate, the adhesive, and the composite patch. The model consisted of 85179 quadratic hexahedral elements having 99 quadratic wedge elements and total number of 85296 degrees of freedom: 67448 in the plate, 4462 in the adhesive layer, and 8924 in the patch. The aluminium plate had three layers of elements in the thickness direction, the adhesive had only one layer of elements through thickness and the patch had two layers of elements through thickness.

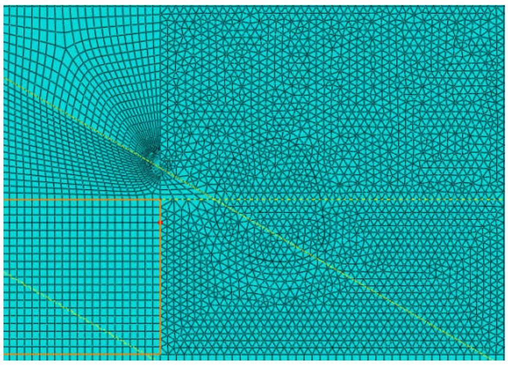

Fig. 3 Mesh of the plate near the corrosion and inclined crack

3. Results and discussions

This criterion is satisfied when the maximum principal strain in the material reaches the ultimate principal strain. For each failure criterion an ultimate strain will be defined and the corresponding damage zone size at failure determined. Under damage zone theory, we assume that the adhesive joint fails when the damage zone reaches a certain reference value. The damage zone can be defined by either the stress or the strain criterion. The strain criterion is more appropriate when the adhesive exhibits significant nonlinearity. There are two modes of failure relevant to the adhesive joints: interfacial and cohesive failure. In the interfacial mode, the failure load of the adhesive joint depends on the interfacial stress near the interfaces between the adhesive and the adherend Ban Chang et al. (2008). However, the adhesive fails when cohesive failure occurs in the joint. Since cohesive failures certainly occurred in the adhesive joint, we recommend using the adhesive failure criterion for the damage zone. The failure criterion, for isotropic materials, such as the Von-Mises and Tresca criteria can be used to better understand adhesive failures. We can also predict the failure of the adhesive joints by using the damage zone ratio method. The damage zone ratio D_R is defined as follow:

$$D_R = \frac{\sum A_i}{l.w} \tag{1}$$

D_R is the damage zone ratio, A_i the area over which the equivalent strain exceeds 7.87% (ultimate strain for the FM 73 Adhesive). It was shown that the FM 73 adhesive fails when the D_R value reached the critical value (D_{Rc}=0.2474) Ban Chang et al. (2008). The damage zone theory was used to evaluate the damage evolution in the adhesive layer. The area of damaged zone is presented in grey color.

The adhesive is the fundamental element for the fixation of the patch, its main role is to ensure good adhesion and ensure the transfer of load from the plate to the patch. This material is the weak point of the repair. In fact, the majority of damage observed in repaired structures is due to the adhesive. Its rupture or its detachment causes the detachment of the composite patch. The influence of the adhesive shear modulus on the variations of the damaged areas is shown in figure 3. For a crack size a = 30 mm, a loading value of 200 MPa, an adhesive thickness e_a = 0.15 mm and a patch thickness e_p = 0.15 mm. The study of the effect of varying the adhesive shear modulus was highlighted.

3.1 Effect of the shear modulus of the adhesive on its damage

The influence of varying the adhesive shear modulus on the damaged area is shown in Fig. 4. The increased the adhesive shear modulus leads to a decrease in the damaged area. This decrease is significant and more noticeable at the crack than at the edges of the patch. We can see this area which is represented in gray color.

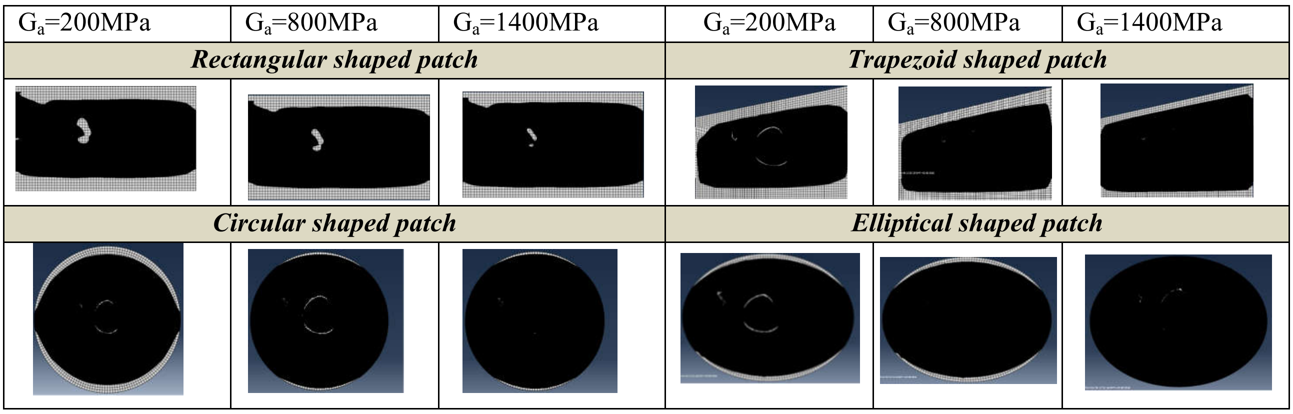

Fig. 4 Damaged area for different of the patch shapes and for different adhesive shear modulus (a) Ga = 200MPa, (b) Ga = 800MPa and (c) Ga = 1400MPa

3.2 Effect of the adhesive shear modulus on the change of the damaged area ratio D_R

Figure 5 shows the variation in the damaged area ratio DR as a function of the adhesive shear modulus (rectangular, trapezoidal, circular and elliptical). Note that increasing the adhesive shear modulus results in a decrease in the ratio DR. All values of the damaged area ratio DR do not exceed the critical value (D_{Rc} = 0.247) regardless of the adhesive shear modulus and regardless of the shape of the patch. The maximum value of D_R = 0.217 is obtained for a shear modulus Ga = 200MPa and decreases to D_R = 0.15 for Ga = 1400MPa for the rectangular shape.

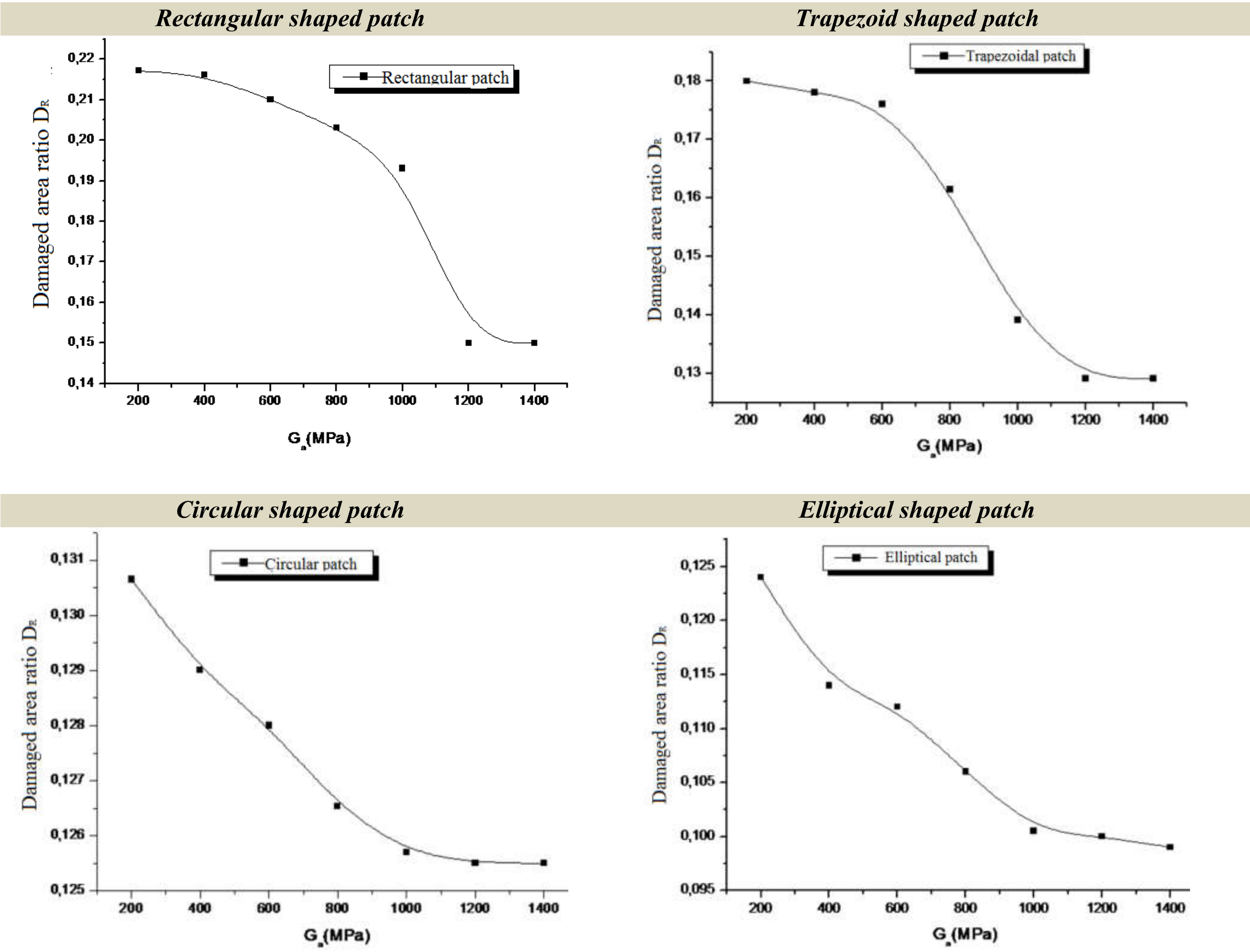

Fig. 5 Variation of the damaged area ratio versus the adhesive shears modulus.

3.3 Comparison of D_R for different patch shapes

Figure 6 shows the influence of the adhesive's shear modulus on the damage area ratio for different patch shapes. Note that all the curves have the same behaviour, the more we increase the values of the adhesive shear modulus, and we observe a decrease in the ratio of the damaged area. It can be concluded on the basis of these results that the elliptical shape is the best for repair because the D_R values obtained are the lowest compared to other shapes. For all values of D_R are lower than the critical value.

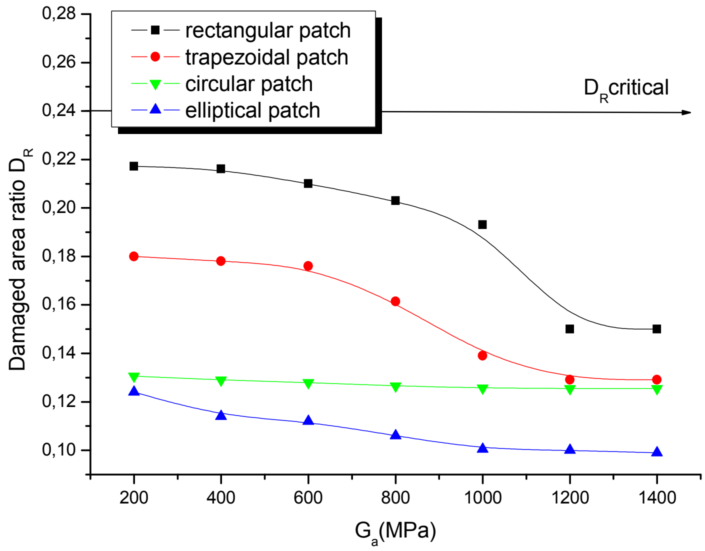

Fig.6 Ratio of damaged area vs the adhesive shear modulus for different patch shapes.

3.4 Effect of the adhesive shear modulus on the variation of the J integral

Figure 7 shows the evolution of the J integral as a function of the adhesive shear modulus for a crack inclined at an angle θ = 30° with respect to the horizontal. Note that by increasing the adhesive shear modulus, we observe a decrease in the J integral in the case of an elliptical patch. For the three remaining shapes (rectangle, trapezoid and circle) the variation in decrease is not very significant, and the curves take the form of horizontal straight lines. For the value of Ga = 200 MPa the J is worth (1.7 and 3.2). 10^{-5} MPa.m respectively for the circular and the elliptical and the value of J is worth (0.75 and 1.1). 10^{-5} MPa.m for those rectangular and trapezoidal. This allows concluding that the rectangular shape is the best.

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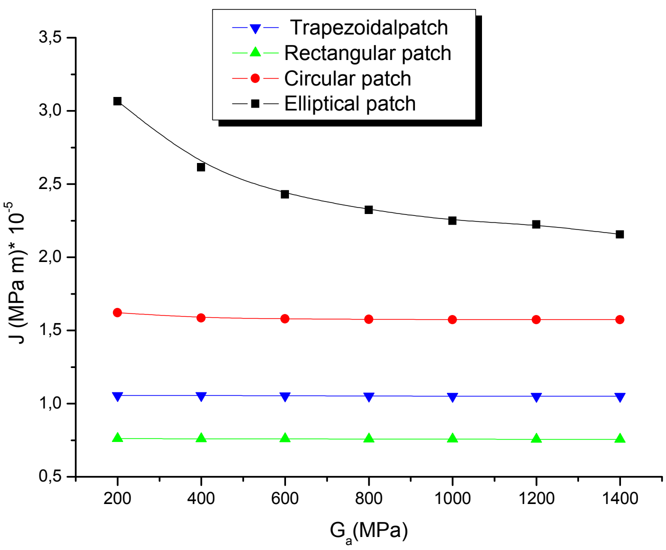

Fig.7. Variation of the J integral as a function of the adhesive shear modulus (a = 30mm, θ = 30°)

4 Conclusion

The results are obtained using the finite element method of a corroded and cracked plate with an inclined crack "mixed mode", repaired by composite. The behavior of the J integral and the distribution of damaged areas in the adhesive led to the following conclusions:

• The more the values of the adhesive shear modulus are increased, the damaged area ratio decreases.

• By increasing the adhesive shear modulus, we observe a decrease in the J integral.

• For the repair of cracks, the rectangular shape is the best because it gives the lowest values of J, the elliptical shape is the best because it allows to obtain low values of D_R.

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