Influence of Geometrical Parameters and Mechanical Properties of Patch Repair of Structures Damaged by Fatigue

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***Abstract*—Strengthening by bonding composite patch is an easy method and showed its reliability especially on aluminium alloys. But the glue that enables secure the reinforcement substrate is still the weak point of the reinforcement of composite materials. Indeed, the majority of the deficiencies found in the structures and repaired are due to the glue. These failures are mainly due to stress transfer from the substrate to the composite patch. Zone transfer effort leads indeed to a peak shear stress near the free edge of the patch. The calculation of stress distributions is therefore important to provide a suitable strengthening solution. The fatigue study allows us to highlight the influence of the distribution patch on the extended life of pre-cracked mechanical structures. Moreover, for a full analysis we must study the influence of various considered parameters set during repair by bonding composite patch.**

***Index Terms*—patch, composite, collage, repair**

I. Introduction

All Mechanical parts and structures, used and handled daily, are all made of a given material, chosen for its good adaptation to the function of the object, and the process used to give it the desired shape. The concept of material is strictly separated from the potential value of the substance to realize an achieved part. Then the material is a base component of the structure that must resist the varying loads. Composite materials, in common sense, is a set of synthetic materials designed to be implemented primarily in structural applications, so that the mechanical feature becomes dominant. These materials are more applicable for the implementation of structural parts of various sizes in many industries such as aerospace, biomedical... etc. For this, it has become inevitable to have a best understanding of these materials in terms of microstructure and mechanical properties, in order to follow their evolution under the action of stress; which allows identifying the phenomena of damage, their initiation and development until failure. Many studies have emerged in recent decades dealing with the problem of damage of composite materials and the methods of repair. We can cite, as an example, the works of Erdogan and Arin [1] and Ratwani [2].

The advantage of using a two-dimensional patch was first treated analytically both by Rose [3] and Soutis [4]. This repair technique also interested other researchers such as Atluri [5], and Bottega Loia [6]. Their contributions concerned the design and analysis of repairs either by riveting, bolting or gluing. In parallel, other efforts in the development of analytical methods for the repair of composite structures have also been made in recent decades, including the works of Engels and Becker [7] and those of Oterkus *et al.* [8].

Various repair methods exist, including the establishment of patches bolted or riveted. The disadvantage of these methods lies, however, in the singular stress field that appears in the connections. To avoid stress concentrations, a possible solution is to stick a composite patch on the defective area of the structure to strengthen more the damaged area and delay the phenomenon of rupture and subsequently increase the life of structure.

The aim of our work is to show the effectiveness of the repair of damaged materials as a promising solution. As composite materials are different from conventional materials by their lightness and high strength, they will not be recovered after damage. For this reason, we have chosen to deal in our contribution to restorative approaches, represented by the bonding of a single joint or preventive reinforcement of the structure with a patch stuck on one side (single lap).

The model used in this study is simplified to an aluminum plate containing a crack opens out flat, repaired by gluing graphite epoxy composite patch. This structure is subjected to a tensile stress in simple distributed load. In addition, for the different configurations of the stress intensity factor and the number of cycles to rupture is analyzed by simulation by using the code of calculation FRANC2DL.

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II. Conceiving a Repair

The conception of a repair shall verify its static strength, its durability and its function so that the whole assembly operation responds to a good functioning depending on the existing substructures. The initial design of the patch should be consistent with the geometry of the structure to be repaired, and should not cover the existing fasteners that require removal in the future [9]. A good design of a repair must meet the following points: The geometry of the patch (size and shape), the choice of patch material, the choice of type of repair, pre-installation.

III. Repair Installing Facility

The Some primary considerations should be made for the installation of a repair operation such as: surface preparation, heating, pressurization methods, the process of inspection [10]. The surface preparation is necessary for compatibility of the patch and the structure to be repaired, on one hand, and a good adhesion of the patch in order to improve the strength and durability, on the other. The operation is based on two techniques that are most effective: a phosphoric acid anodizing (PAA), and sanding of silane (GBS). First, the surface contaminants (paint, sealants, etc.) are removed by abrasive wear and cleaning products. Then, we proceed to electro-chemical changes induced by the effect of anodizing, after that, we move to a light sanding that involves stripping for aluminum oxide, and the application of a coupling agent binds to both the structure and the adhesive [11]. The pressure applied during the drying, reduces voids in the bond line and ensures contact between the patch, the adhesive, and the structure. The most common technique is pressurizing the vacuum bag [12].

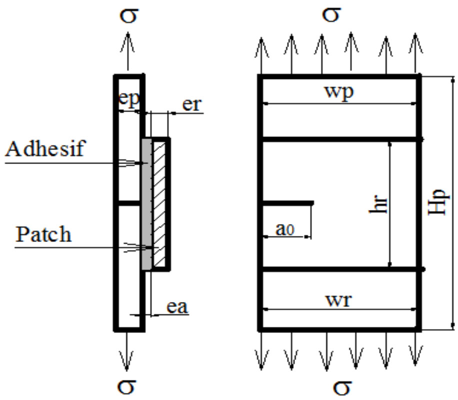

Figure 1. Geometrical model of the structure.

IV. The Geometric Model

The aluminum part in question, has the following dimensions: length=203mm Hp, wp=width 76mm, thickness ep=2mm, and its mechanical properties: modulus of elasticity E=72000MPa, Poisson's ratio=0.33. The proposed model contains a through crack of initial length a0=10mm, oriented perpendicular to the direction of loading. It is repaired by bonding with an adhesive type epoxy bicomponent by a thickness of the order of ea=1mm and a patch of graphite-epoxy composite type, which dimensions are: length=76mm wr, hr width=51mm, er=2mm thickness. The plate used is subjected to a tensile load in single and uni-axial intensity σ=180MPa (Fig. 1).

The mechanical properties of the different elements of this study are summarized in Table I.

TABLE I. Type Sizes for Camera-Ready Papers

	Plate	Patch	glue
Nature	AL2024-T3	Graphite/epoxite	Epoxyde bicomponent
E1(MPa	72000	172370	473
E2(MPa)		10340	
ν12	0.33	0.3	0.018
G12(MPa)		4280	185.2

A. *Effect of the Patch on the Stress Intensity Factor*

Fig. 2 shows the variation of the SIF of a crack with and without the presence of the patch. It should be noted that the presence of the patch significantly reduced the value of the SIF It is clear that the SIF of the repaired crack is very small in comparison with the SIF of the unrepaired one. Compared with the case without patch, we see that the value has decreased to a large percentage. This can be explained by the fact that the patch absorbs the stresses in the cracked plate and this regardless of the length of the crack, but this provided that the crack is covered by the patch along its spread.

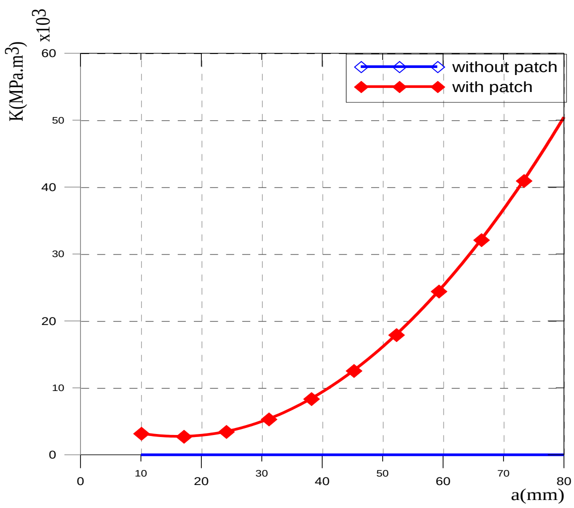

Figure 2. SIF variation depending on the length of crack.

B. *Influence of Geometrical Parameters of the Studied Assemblage*

The main geometrical parameters that can change the behavior of the assembly are: the thickness of the adhesive, the thickness of the plate, the length and width of the plate [13]. Fig. 3 shows the evolution of the SIF according to the crack length for different values of the thickness of the adhesive. The stress intensity factor at the crack tip is proportional to the thickness of the adhesive joint. Stress concentration decreases when decreasing the thickness of the adhesive joint (Fig. 3)

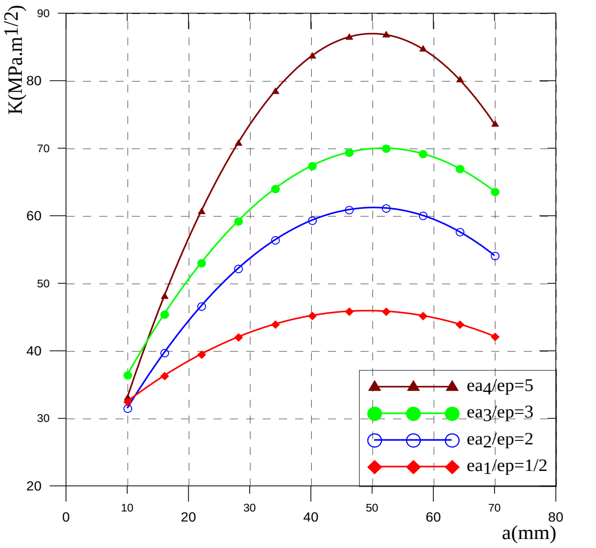

Figure 3. Variation of SIF K according to the variation of the thickness of the joint of glue.

So, for a good transfer of force from the cracked plate to the patch and in order to reduce the stress concentration, we use thin glue joints. However, the use of thinness causes a charge transfer to the patch but increases the risk of failure of the link.

Fig. 4 shows the variation of the SIF based on the crack length for different values of report wr/wp. SIF is slightly affected by the width of the patch, there is a linear change when the values of the minimum overlap width does not exceed too much the dimensions of the crack

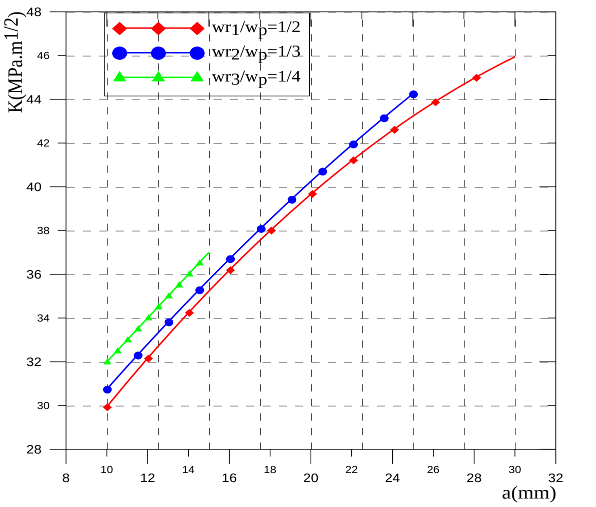

Figure 4. Effect of the width of the patch on the stresses intensity factor.

The deviation of the crack may be caused by an increase in the length of the edge, associated with an increase of the roughness of the fracture surface. For the influence of the length of the patch on the SIF, we notice a reduction in the tip of the SIF of the crack due to a decrease in the length of the patch and therefore decreasing the covering surface.

Unlike the previous case, where the increase of the top surface was the width of the plate (Fig. 5).

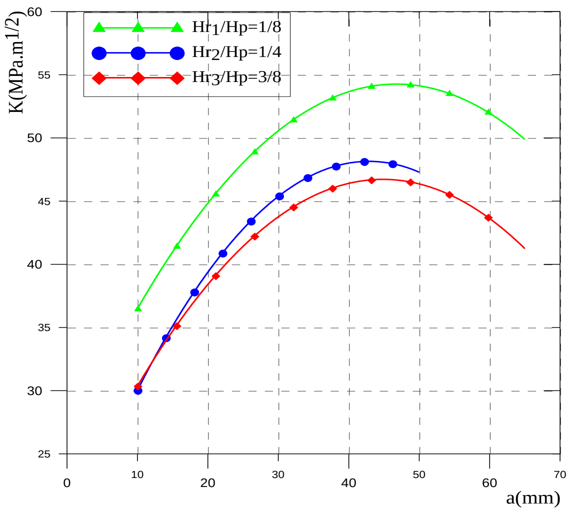

Figure 5. Effect of the length of the patch on the SIF.

For the case of the influence of the length of the patch on the lifetime of the fissured structure, the number of cycles at break NR decreases when the top surface increases by increasing the length of the plate of the patch (Fig. 6).

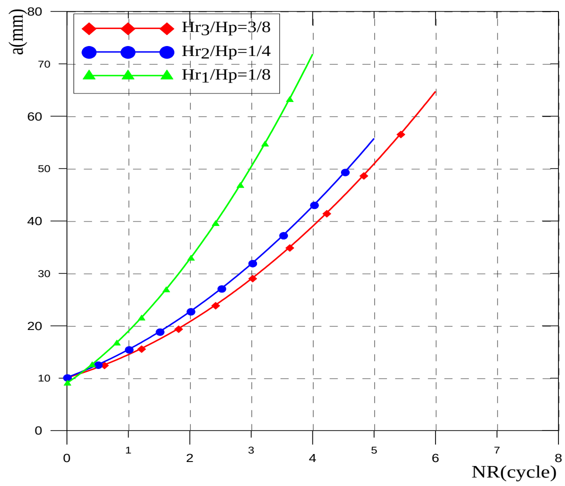

Figure 6. Influence of the patch on the lifetime of the plate.

So, the life decreases to about 37%. This obliges us to seek an optimum value of the length of the patch, if one tries to increase the area of transition constraints out of the damaged plate to the patch. However, there is a cap for optimal overlap length because only the ends of the seal actually work, while the center barely supports any effort.

C. Influence of the Nature of the Materials of the Patch

The main parameters of the patch, which may change the mechanical behavior of the adhesive bonding of the reinforcement by composite patch of a damaged structure: the nature of the used patch, identified by its crosswise elastic modulus Ga, the type of the used composite characterized by its modulus of elasticity. Table II summarizes the mechanical properties of the chosen materials, where E1, E2 and G12 are the longitudinal Young modulus, transverse Young modulus and the shear modulus of different used composites.

TABLE II. MECHANICAL PROPERTIES OF USED COMPOSITES

	Composite materials of epoxyde matrix and reinforcement:		
Properties	Fiberglass	Carbon fiber	Fiber of Kevlar 49
E1 [GPa]	46	159	84
E2 [GPa]	10	14,4	3,6
G12 [GPa]	4,6	4,9	2,1
ν12	0,31	0,32	0,34
	Comp1	Comp2	Comp3

Fig. 7 shows the variation as a function of the SIF composite type.

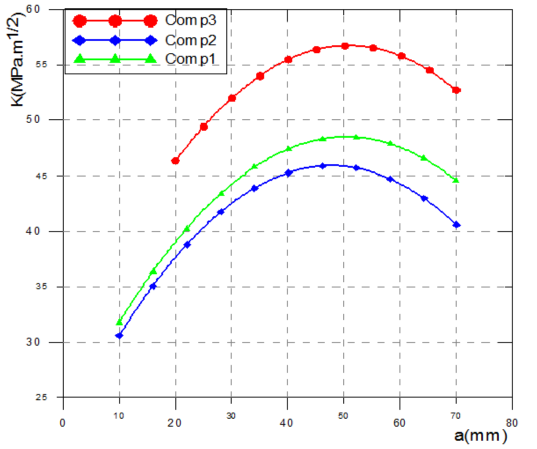

Figure 7. Effect on the nature of the composite stress intensity factor.

The composite comp2 has a positive effect on reducing the SIF deep in the crack; it is also due to its mechanical properties.

Fig. 8 shows the number of cycles estimated at the rack for each composite used to strengthen the damaged plate rupture.

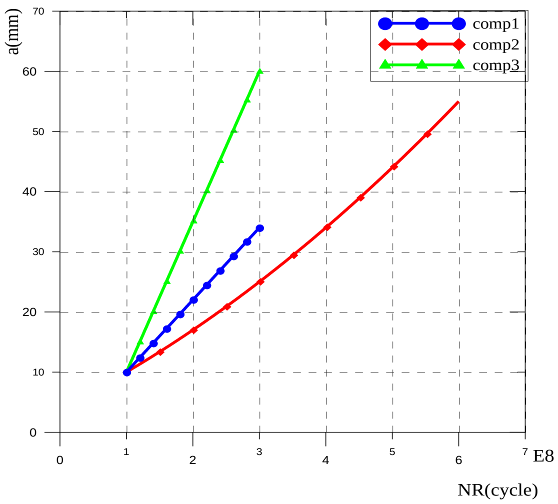

Figure 8. Influence of the nature of the composite on the lifetime of the plate.

According to Fig. 8 a significant delay in crack propagation is found, so the life of the damaged structure will be improved. This delay at break increases with an increase in elasticity of the composite properties, especially the longitudinal modulus of the composite comp2 which has a beneficial effect on the life of the cracked plate.

The nature of the glue is considered as one of the factors that may influence the effectiveness of the patch. The shear modulus G is the property defining the stiffness of the adhesive. We will deal in this part of its influence on the strength of the patch. We compared the mechanical behavior of bonded joints with four types of adhesives, shown in Table III according to their cross elasticity modules

TABLE III. THE SHEAR GLUE USED MODULES

	glue1	glue2	glue3	glue4
Ga [Mpa]	171,51	146,82	220,67	196.04

Fig. 9 shows how the SIF depends on the evolution of the cross elasticity modulus of the adhesive.

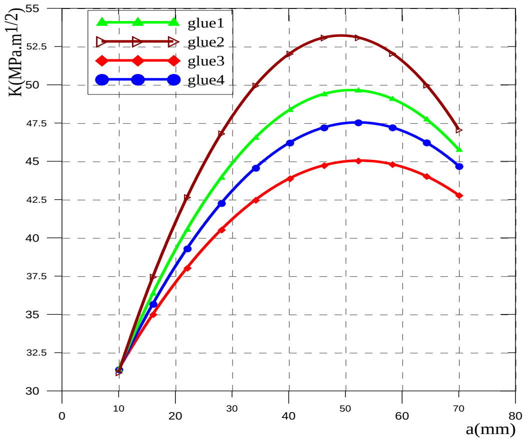

Figure 9. Effect of the nature of the glue on the SIF.

More the shear modulus of the adhesive increases, the more SIF knows a clear decrease. This is due to the force which occurs in the transfer of the adhesive joint. That is to say, more glue with high cross elasticity is used, perfect is adhesion between the cracked plate and the patch; which creates a good stress transfer.

For the lifetime of the cracked plate, Fig. 10 shows diagrammatically the effect of the shear modulus of the adhesive on increasing the operating life of the pre-cracked structure.

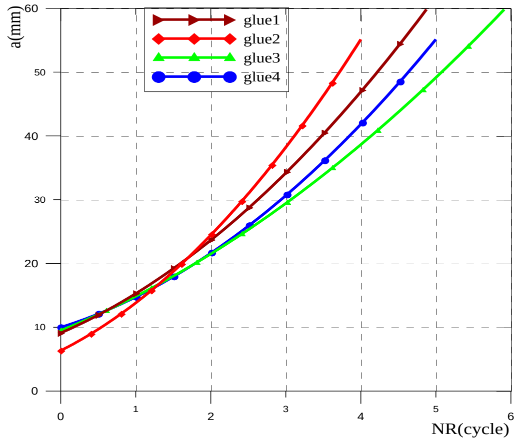

Figure 10. Effect of the nature of the adhesive on the life of the plate.

We note that the higher the shear modulus of the adhesive, the more important is the life of the plate.

V. Conclusions

The fatigue study has highlighted the influence of patch repair on the life of a mechanical structure. Moreover, we studied the influence of various parameters implied in a composite patch repair. We can summarize the results as follows:

- The SIF mode I is greatly reduced by the presence of patch.
- To reduce the stress concentration, use glue joints of low thicknesses. However, the use of very thin supports causes the charge transfer to the patch but increases the risk of failure of the link.
- The SIF K decreases as the thickness ratio ec/ep increases, i.e. when the thickness of the composite plate increases.
- The maximum value of the stress at the crack tip increases as the overlap width decreases.
- Reduction of the SIF crack point due to a reduction in the length of the patch and therefore the reduction of the top surface.
- The composite comp2 has a beneficial effect on reducing the intensity of the SIF crack tip; this is also due to its elastic properties.
- If the shear modulus of the adhesive is more important, the SIF will know a clear decrease.

Finally, we can conclude that the technique of composite patch repair is a very effective method for strengthening damaged structures fatigue cracking, as long as you master the technique and optimize the various patch parameters.

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