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Mechanical behaviour of steel pipes reinforced with composite materials and steel

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Abstract

The metal pipes are particularly vulnerable to internal and external constraints or geometric instability, and their sizing is effected by using simplified rules. Indeed, these pipes are very sensitive to the slightest imperfection or initial geometric operation (accidental loads, temperatures, etc.). Taking into account the various damage generally leads to a loss of bearing capacity. To reserve the potential burden of these pipes, it is necessary to strengthen them. In this study we have made the strengthening of steel pipes with metallic materials and composites in the presence of compressive stresses. One or more layers of composite are bonded to the discontinuity of the pipe. The analytical treatment for this type of problem is complex and therefore we use numerical modeling using the code ABAQUS. The results show that the correct fiber orientation relative to the advance of the crack affects a significant effect on reduction of FIC. The properties of the membership must be optimized to increase performance of the repair piece over. Reducing the FIC becomes important when others decrease.

1. Introduction

The metal pipes are particularly susceptible to internal and external constraints or geometric instability, and sizing takes place by having recourse to simplified rules. Indeed, these pipes are very sensitive to the slightest initial geometric imperfection or operation (accidental loads, temperatures, etc.). The taking into account various damages generally lead to a loss of bearing capacity. In order to reserve the load potential of these pipes, it is necessary to strengthen them. In this study we realized the strengthening steel pipes with metallic and composite materials in the presence of compressive stresses .One or more layers of composites are adhered to the discontinuity of pipe.

The results show that the right orientation of the fibers relative to the advance of the crack influences a huge way on reducing the stress intensity factor (FIC). The properties of the adhesion must be optimized to increase the performance of the piece repair compared. The reduction of the FIC becomes more important as it decreases. Recently, the use of adhesives is accepted as a process of repair of structures to increase the lifetime of damaged components. Metal or composite parts are glued to a single face or both at once cracked for part for extending its lifetime service, To investigate the thickness effects on fatigue crack propagation properties [1]. Repairing cracks by bonding made of composite material patch has proved its effectiveness in reducing the stress intensity headers cracks, is to reduce speed of crack propagation. This method is employed to repair aging aircraft components. Numerous studies have been conducted to develop the technology of bonding of composite patches in aeronautic structures. This paper presents results of experiments designed to measure the crack growth rates in different materials [2]. It is well known that the finite element method gives with high accuracy the stress intensity factors at the crack tip. Among the authors using the method of calculation of factor in the case of reinforced cracks may be mentioned [3,13]. A study was carried out on the repair of a crack emanating from semicircular lateral notch by a semi-circular composite patch [13]. The purpose of this study is to analyze the behaviour of a reinforced crack in a steel pipe in mode I and mode II by the finite element method. The steel patch identical to that of the pipe is used in crack repair. Different authors [5] have shown that, in practice the parameters influencing the performance of the repair are the properties of the patch and of the adhesive. For this purpose, the effects of the shear modulus of the adhesive, the thickness of the adhesive and the thickness of the patch are examined with respect to the variations in the stress intensity factor.

1.2. *Geometric model*

In this modeling, one considers a steel pipe having the following dimensions: length, diameter, and thickness. A crack of length located in the middle of the pipe and perpendicular to the plane of stress is assumed. The pipe considered is subjected to diametrical compression in the vertical directions under the applied stress of amplitude $\sigma = 100MPa$. as well as, mechanical and geometrical characteristics of the pipe and patch are respectively denoted by the indices p and r. The crack is repaired by a patch made of metallic material, and by a composite patch, and another laminated composite patch with four plies varying from 0 °. 30 °. 45 ° and 90 °, the purpose of this variation is to notice which of the orientations is effective, the pipe is of dimension: Length L, and thickness er, The properties of the patch material are: Young's modulus and poisson coefficient. The properties of the adhesives are: Shear modulus and thickness, given that the geometry of loading is symmetrical half structure is sufficient for the numerical study. Figure 1 shows the symmetry of the geometric model.

Length pipe L(m)	Diameter pipe d(mm)	Thickness e_p(mm)	Length patch L(mm)	thickness er(mm)	Thickness ad e_a (mm)
1	10	1	50	1	0.27

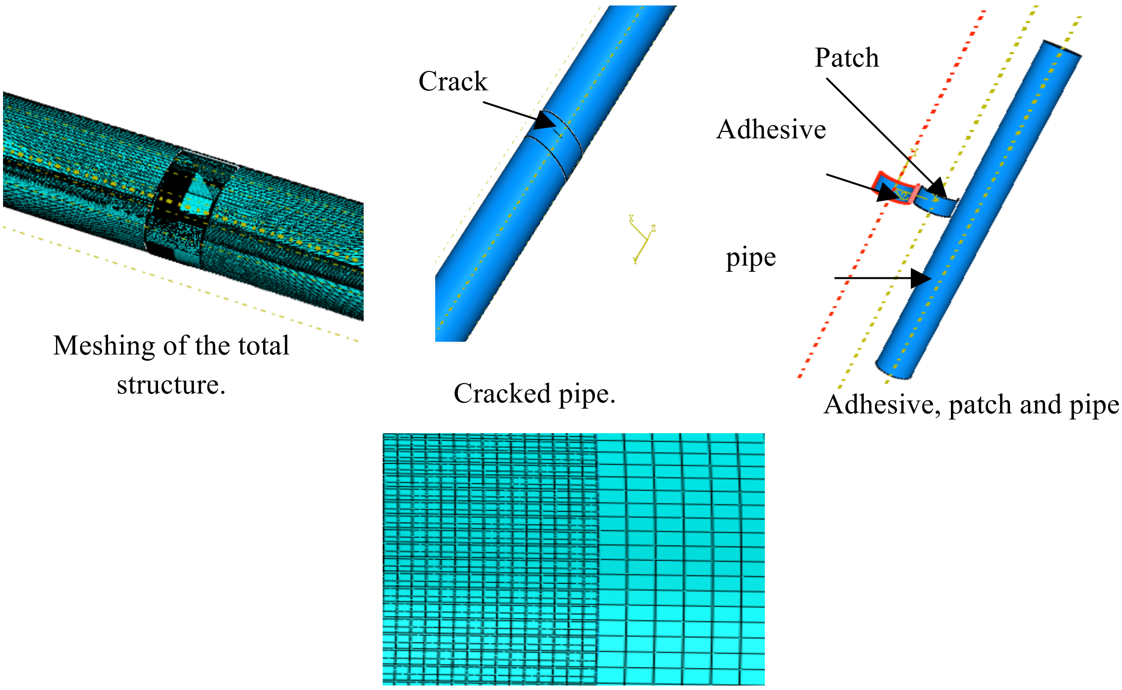

Figure1. Geometric model and mesh pipe (pipe, adhesive and patch)

The complete structure is composed by a number of six (6) nodes
The maximum number of increments in this step is 100
819108 elements have been generated on instance: Adhesive
819108 elements have been generated on instance: Patch
12100 elements have been generated on instance: Pipe

Table 1. Mechanical properties (pipe, patch and adhesive)

	E_1 (GPa)	**E_2 (GPa)**	**E_3 (GPa)**	ν_{12}	ν_{13}	ν_{23}	**G_{12} (GPa)**	**G_{23} (GPa)**	**G_{13} (GPa)**
Patch Glass/epoxy	150	25	25	0.21	0.21	0.21	7.2	5.5	5.5
Adhesive FM 73	1.0713			0.33					
Steel Pipe	210			0.3					
Aluminum Patch	69			0.34					
Stainless steel patch	193			0.27					
Patch cupro aluminum	117			0.3					

The specification of the pipe is done by applying symmetrical boundary conditions. The behaviour of the crack is considered to be unstable. To repair the unstable aspects we use a patch and we tied on one side as on both sides of the pipe is practically impossible. The transfer of tensions and deformations of pipe to the patch is assumed that the displacements and tension at the interface of the pipe and patch are continuous.

1.3. *Finite element modeling*

We used a finite element code named ABAQUS for the numerical modeling work. This code was originally developed at the University of USA is based on the theory of linear and non-linear failure mechanics [4-14].

A three-dimensional modeling by finite elements, or the development of a mathematical model, is generally very complex for this type of structure.

2. Influence of patch thickness

The parameters of the rupture are influenced by the rigidity of the patch, the size of the attachment region and the toughness of the adhesive [3- 12]. The material of the patch influences variation of the stress intensity factor immediately. To highlight the process of repairing a crack, we chose three patches identical geometric shapes having different mechanical properties. The work is to vary the location and shape of the crack repaired with varying thickness of the patch while maintaining the same mechanical characteristics of pipe and patch.

2.1. *1st case Laminated composite patch.*

This study deals with the influence of the thickness of the patch on the broad parameters of the rupture Figure 2.1 and figure 3.2 showed the effect of the thickness of the patch on the variation of the stress intensity factor of the crack for different orientations of glass / epoxy which are 0 °. 30°. 45 ° and 90 °. It can be seen that the increase in the thickness of the patch reduces the stress intensity factor of the crack asymptotically.

The glass / epoxy of the orientations 0 °. 30°. 45 °, and 90 ° allow a better absorption of the stresses transmitted by the crack, and tend towards a value of zero. The rate of reduction of the stress intensity factor depends on the thickness of the patch. However, we note that the thicknesses of the patch in glass / epoxy, 1mm create a strong reduction in FIC (stress intensity factor) and stabilization of the latter tends to a constant value. The same constraints are made for the integral contour (Jii).

2.2.*2nd case Composite Patch*

The fig 4 represents the variation of the stress intensity factors K_I and K_{II} as a function of the thickness of the composite patch in traction mode, this curve shows that the two FICs decrease when the thickness of the composite patch increases, both of the stress intensity factors can be replaced by the contour integral J or the energy restitution contour J presented by the two equations I and II.

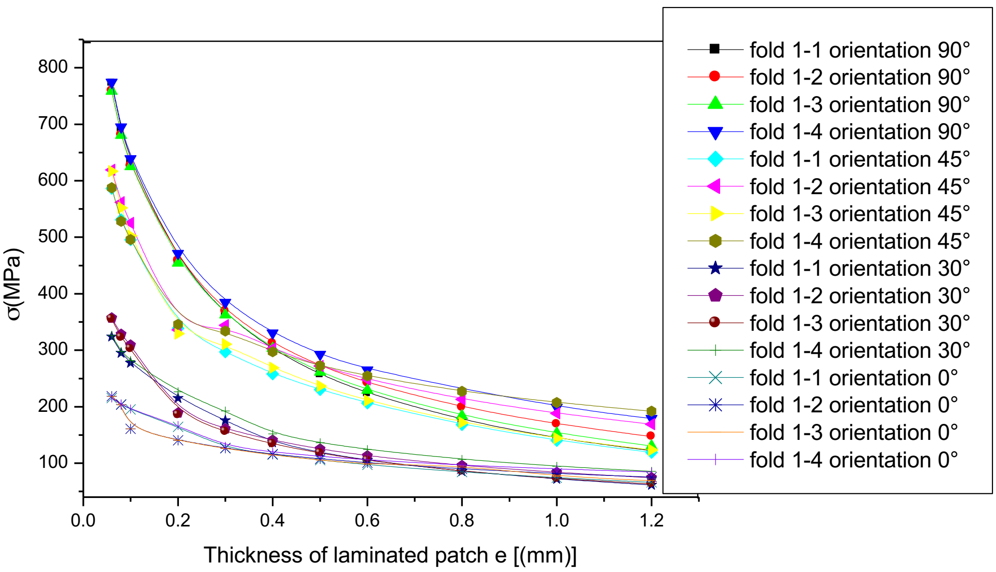

Figure 2. 1 case Influence of the thickness of the laminated patch 0 °. 30 °. 45 ° and 90 ° the max von mises picture constraint

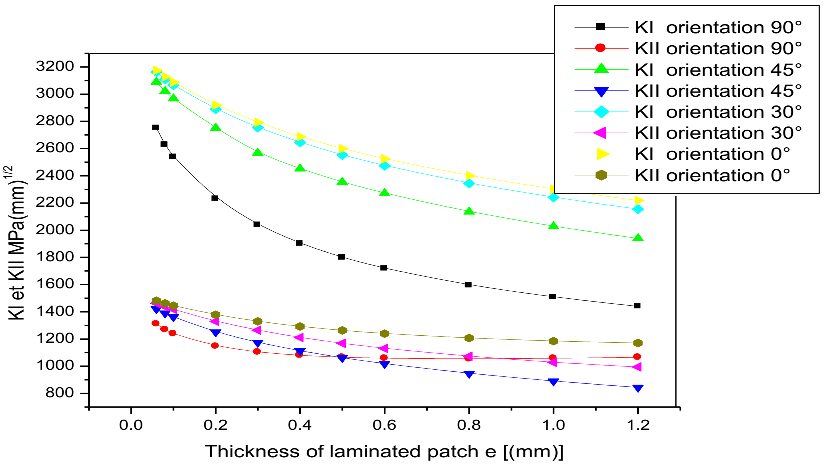

Figure 3. 2 cases Influence of the thickness of the laminated patch 0 °. 30 °. 45 ° and 90 °CIF on K_I and K_{II}

$$\boldsymbol{J = \frac{1}{E}(K_I^2 + K_{II}^2)} \qquad \mathbf{I}$$

$$\boldsymbol{J = \int_A^c \lambda(s).H.qdA} \qquad \mathbf{II}$$

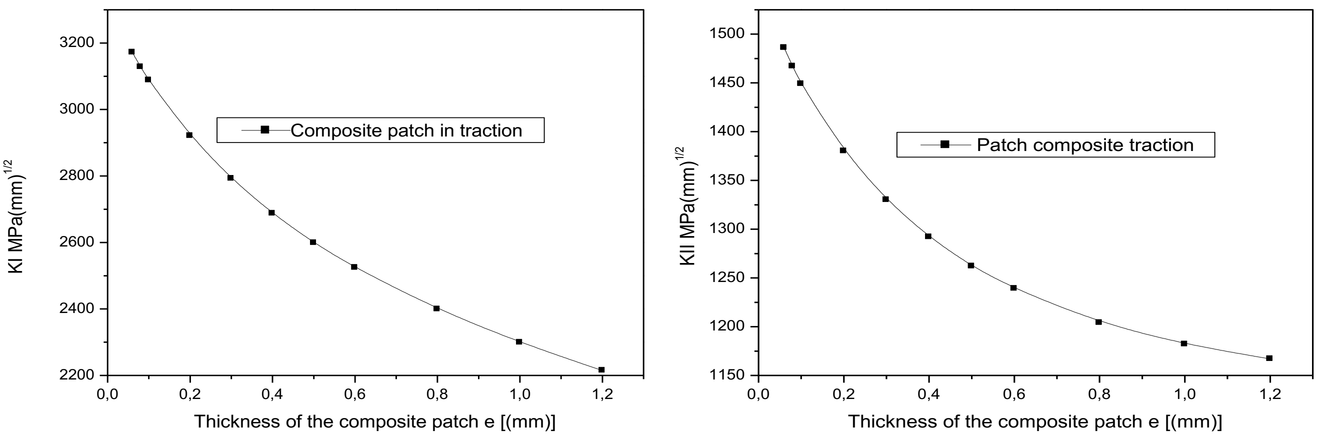

Figure 4. Influence of the thickness of the composite patch on the variation of the FIC.

2.3 *cases steel patch*

a) Stainless steel

b) Aluminum Steel

c) Copper-aluminum

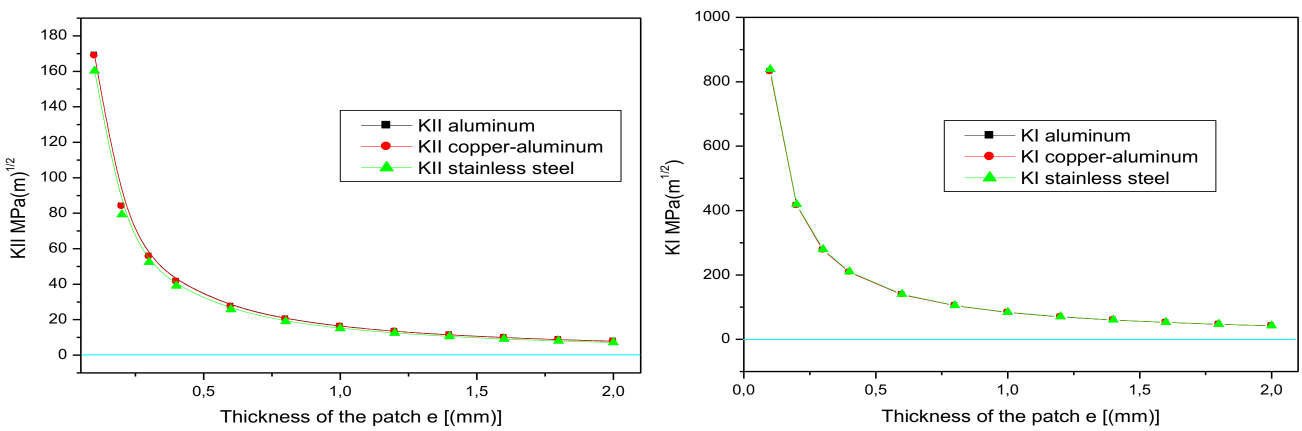

Figure 5. Influence of the thickness of the steel patch the variation of the FIC.

For the case reinforcement patch steel, Figure.5 it has taken three cases of figures whose Young's modulus and poisson are different, of a material with to another. It has been found that the variation of the FIC is always inversely proportional to the thickness of the patch, which reduces the FIC (stress intensity factor) to a value close to the constant and tends towards the value zero. The main point that highlighted the two factors K_I and K_{II} is the reduction of the FIC in mode I which is very important with respect to mode II, therefore whatever the nature of the patch the increase of the FIC is always inversely proportional to the thickness of the patch as well for the composite patch figure 4.

3. Influence of the thickness of the adhesive.

The effect of the thickness of the adhesive plays a decisive role on the balance of the patch reinforced cracks. FIG 6 shows the reduction of the FIC in mode I and II as a function of the crack length of length 2a = 30 mm, for different values of the thickness of the adhesive ea. We can see in this figure that a reduction the thickness of the adhesive decreases in a way like another , the value of the stress intensity factor this can mean a low thickness of the adhesive is desirable to repair cracks. The shape of the stress intensity factor linearly decreases with respect to the increase in the thickness of the adhesive In other words, increasing the thickness of the adhesive results in the rapid convergence of the shape of the stress intensity factor tends to a nearly constant value.

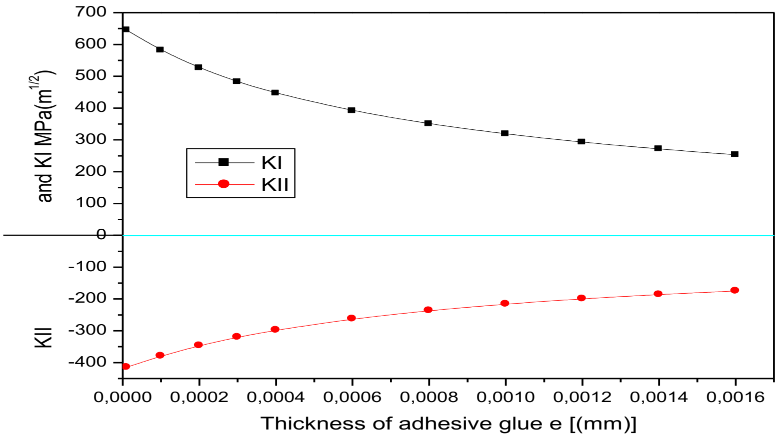

Figure 6. Influence of the thickness of the adhesive on the variation of the FIC

3.1. *Case of internal pressure*

In this part, our study was aimed at varying the thickness of the adhesive, keeping that of the composite laminate patch constant, knowing that the latter had four numbered folds, oriented at 0 °. 30 °. 45 ° and 90 °. To see how the stress intensity factor will be varied at the ends of the crack, we plotted the different curves according to the thickness of the adhesive. The figures below show this variation for the case of an internal pressure of 100 MPa for both modes.

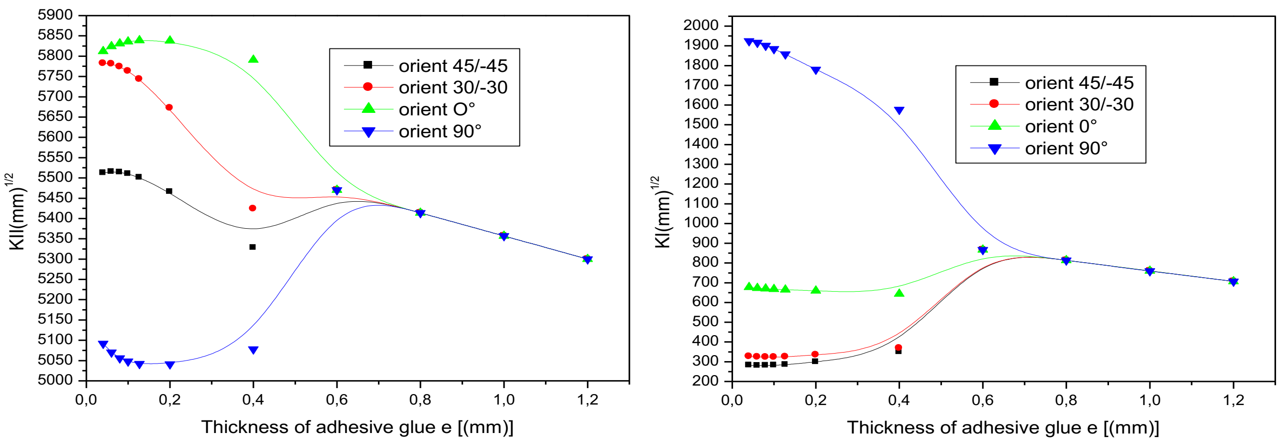

Figure 7. Variation of adhesive glue thickness as a function of the FIC

FIG. 7 shows the variations of the stress intensity factor K_I as a function of the thickness of the adhesive. It should be noted that the FIC decreases for the orientation of 90 ° and for the other orientations of 0 °. 30 ° and 45 °, It reaches an identical value of 800 MPa $(mm)^{1/2}$ and the thickness of the adhesive 0.7 mm above this value, the FIC becomes constant, then the four orientations decrease simultaneously and take the same value, it can be said that after this value the FIC stabilizes and becomes constant for the different orientations, this results from a separation or detachment of adhesive and the patch with the different orientations of the composite patch.
FIG. 7 show the variation of the stress intensity factor K_{II} as a function of the variation in the thickness of the adhesive. We note that the same phenomenon occurs as that of the FIC K_I, but the difference lies in the orientations of the folds. It has been found that the 90°, oriented ply increases and the other plies of orientation 0 °. 30 ° and 45 ° decrease and coincide with the same value identical to the FIC K_I, with a thickness of 0.7 mm, beyond the latter, all orientations stabilize and become constant. It can be concluded that the adhesive and the patch have been loosened. Conversely, in the first case, the orientation at the most important value of the FIC is 0 ° and the lowest is 90 °, the four orientations are similar for the two FICs, and become constant after the value of 0.7 mm. Our remarks are as follows:

- Beyond the value of 0.7mm the two FIKs unfolded for the four orientations, and take the same value.
- The second point is that the orientations for the two FICs are reversed (for the FIC K_I, the orientations of 0 °, 30 ° and 45 ° increase, then decreases except 90 °, on the other hand the FIC K_{II}, The orientations 0 °, 30 ° and 45 ° decrease and the orientation 90 ° increases, then decreases and remains constant with the other three, knowing that the latter are calculated at the same point of the crack.

3.2. *Case of traction*

In this section, we studied the traction case of the pipeline with the same value as that of the internal pressure of the previous case, with an identical crack of the same length as the previous one.
We have varied the thickness of the adhesive, and we have kept the thickness of the patch of composite laminate constant, knowing that the latter had four numbered flats oriented at different angles of 0 °. 30 °. 45 ° and 90 °, with the same geometric shapes as previously.
To see how the stress intensity variation at the crack tip will vary, we have plotted the different curves that represent the variation of the stress intensity factor as a function of the thickness of the adhesive.
The figures below show 8 this variation for the case of traction for the value of 100 MPa.

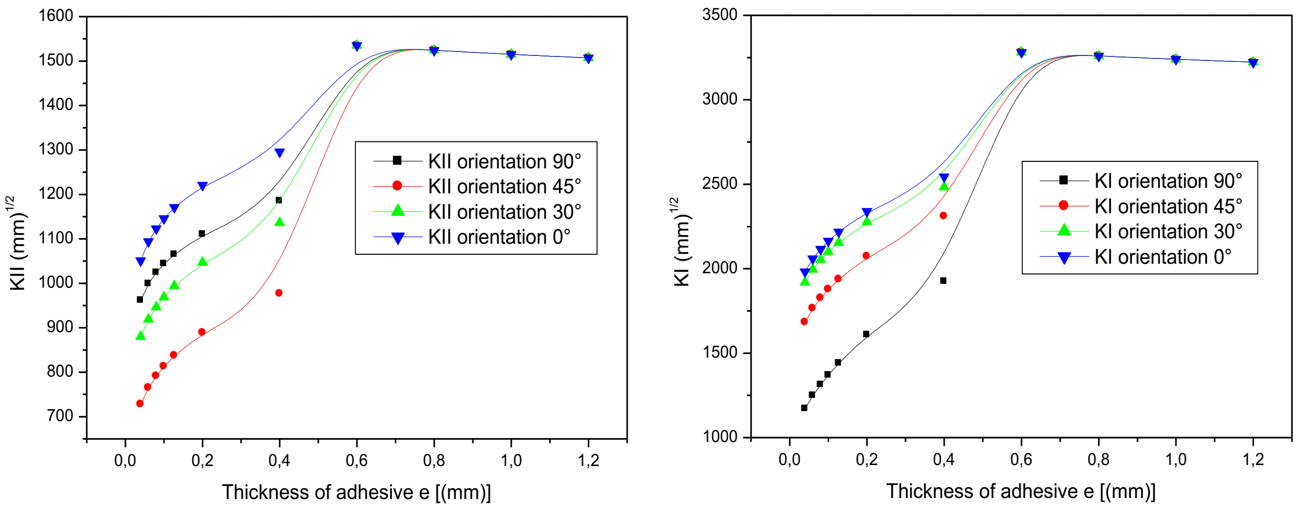

Figure 8. Variation of adhesive glue thickness as a function of the FIC

For the above figures 8 and 9 we have shown the variation of the stress intensity factor K_I and K_{II} as a function of the thickness of the adhesive , it is noted that for the four orientations the curves of the two stress intensity factors believe (Increase) to a thickness value of 0.7mm, then stabilize and become constant. The four orientations are similar for the two FICs We also find that for the two FICs the orientation 0 ° to a very important value in relation to the others, for well assimilated this reflection we have plotted the two curves in the same graph above.

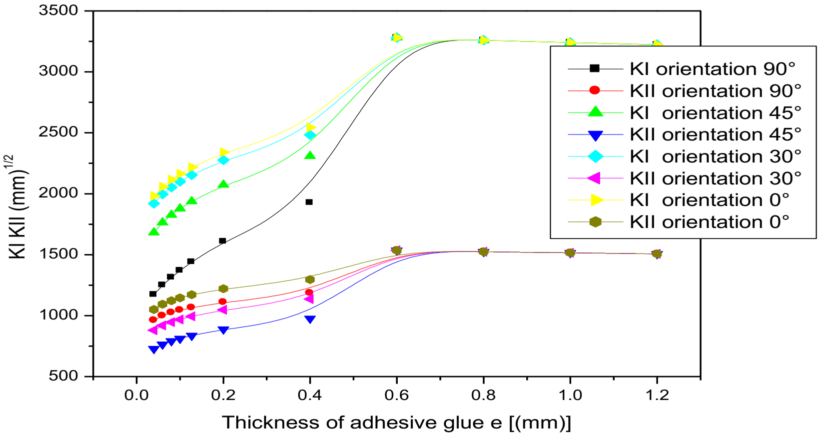

Figure 9. Influence of the thickness of the adhesive on the variation of the FIC, K_I and K_{II}, Case of traction.

4. Influence of shear modulus of the adhesive Ga

Studies have mounted that the best quality adhesive is characterized by a low shear modulus; it reduces the effort transmitted to the adhesive [6-9]. In the case of repaired cracks, the objective is to transmit the maximum stress to the adhesive and consequently to the patch to reduce the energy at the crack tip. Theoretically, it is thus preferable to employ adhesives having a high shear modulus for repairing cracks or defects [7]. FIG 10 shows the variation of the stress intensity factor as a function of the variation of the shear modulus of the adhesive. It is noted that the decrease in the stress intensity factor is inversely proportional to the increase in the shear modulus of the adhesive, but the reduction in the stress intensity factor which is a function of Ga tends to be cancelled when Ga increases indefinitely. In evidence an increase in the shear modulus of the adhesive reduces the adhesive stress, and consequently produces the detachment. For this, the choice of adhesive for the repair of cracks must be optimized to allow the transmission of forces to the patch and avoid failure of adhesion due to the increased efforts of tension in the adhesive layer [8-13].

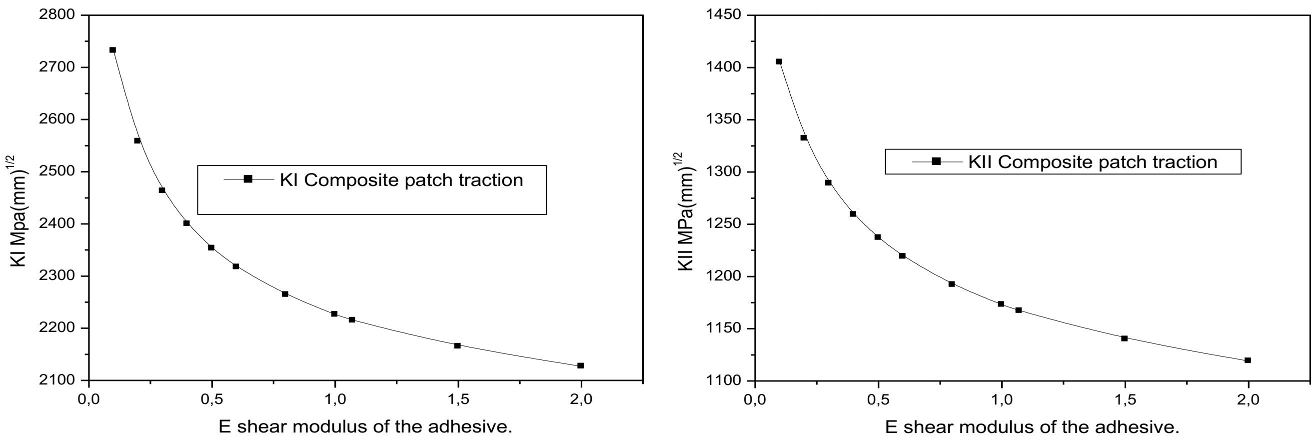

Figure 10. Variation the FIC depending on the shear modulus of the adhesive.

Conclusions

The study of this article is related to the maintenance and repair of pipelines. Many questions were asked in this study and some of them were able to be further explored. A reflection on this subject leads us to develop and use a numerical calculation based on Abaqus 6.14.1 software to optimize and observed how certain parameters vary according to the FIC. The study concerns the repair or reinforcement of pipes damaged and which have cracks, undergoing a load which manifests as a flow of the fluid under pressure of 100bar. For this purpose, patches made of composites or metallic have been chosen as a means of repairing (reinforcement).

The purpose of this study allowed us to behold the variation of the FIC as a function of certain parameters, the propagation of crack in mode I and II, as well as the properties of the materials.

For this purpose, we have presents the following findings:
The main factors involved in dealing with this problem, which is the variation of the FIC with crack propagation, are: the shear modulus of the adhesive, the thickness of the adhesive and the thickness of the patch. The reinforcement of the pipes by composite or metallic patches, delays the propagation of crack.

- The presence of a patch greatly reduces the stress intensity factor which can delay the propagation of the crack and thereafter increasing the life of the structure.
- The stress intensity factor at the tip of the crack is inversely proportional to the increase in patch stiffness and its geometric characteristics.
- The choice of the thickness of the patch is one of the best means of increasing the performance of the repair of structures.
- The thickness of the adhesive layer markedly reduces the FIC, so it is desirable to have a thin for the repair of cracks.
- The choice of the shear modulus of the adhesive layer is very important, it considerably reduces the FIC when it increases.
- We found that for both modes, and for both FICs, we have a detachment of the adhesive glue, and the patch has a thickness of 0.7 mm, which is reflected by the growth of the FIC KI for the orientations 0 °. 30 ° and 45 °, on the other hand the 90 ° orientation decreases, unlike the FIC KII which increases for the 90 ° orientation and decreases for the other orientations of 0 °. 30 ° and 45 °, the 0 ° orientation has the highest value of the FIC.

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