J. Mater. Environ. Sci. 7 (6) (2016) 2137-2147
ISSN : 2028-2508
CODEN: JMESC

Cracked modeling behaviour of a composite panels

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Received 5 Feb 2016, Revised 27 Apr 2016, Accepted 29 Apr 2016
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Abstract
Due to a shock, a composite panel of a naval or aeronautical structure may have a crack. The present work is to model the behaviour of a composite panel having a longitudinal crack subjected to a bidirectional tensile loading. To stop the spread of the crack, we propose to employ stiffeners. This technique optimizes the weight of the panel and to increase its resistance. In this context, we account on the proposal for an ANSYS modeling for the study of the crack propagation in a composite laminate panel. Our modeling take into account the effect of the load intensity, the influence of the presence and location of the stiffeners, the crack inclination angle and the influence of the material properties. Following the satisfactory results obtained by the proposed modeling, our work can be used as a basis for the repair of cracked laminated composite panels after a possible shock.

Keywords: Composite panels, Crack propagation, Stiffeners, Stress, Ansys, Bidirectional load

1. Introduction
The naval, aerospace and automotive construction industry looks increasingly to the use of composite materials. This type of construction may cause shock and hence, cracks arise. In his work, Schijve [1] concluded that small cracks can significantly reduce the resistance of the plates. Indeed, there are many unfortunate examples where cracks have caused the fail of these structures. An important issue in composite panel design for naval and aerospace structures is crack propagation [2,3,4]. Unfortunately, and unlike steel, one of the important aspects of the behaviour of the composites is their resistance to impact and therefore damages and cracks resulting [5,6].

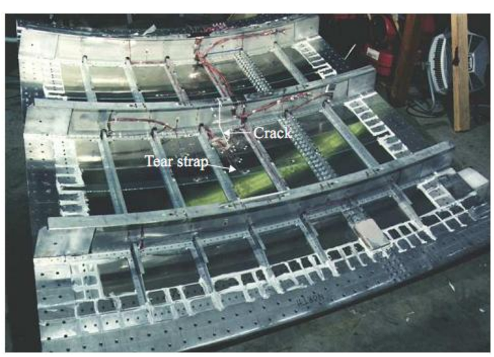

Fig. 1: Cracks in aeronautics construction panels

In the past, when a component of some structure exhibited a crack, it was either repaired or simply retired from service. Such precautions are often deemed unnecessary, not possible to enforce, or may prove too costly. Given a cracked plate, an incremental approach to predict the future crack path can then be implemented, [7,8].
The study of tensile strength of the composite materials is a much more complex than analysis of elastic or viscoelastic properties. Indeed, the development of a crack depends on several parameters intrinsic to the material such as the geometrical and mechanical properties of the structure or extrinsic as the extent of the crack or the nature of the loads applied [9]. All these parameters should be taken into account in the computer simulation, so as to allow the study of the static crack growth in a stiffened panel. According to the process of degradation of composites, we can have the micro cracks appear in the matrix, the fibers that break (brittle or ductile fracture), the debonding are created at the interfaces of lamination appear without causing the ruin of the room.

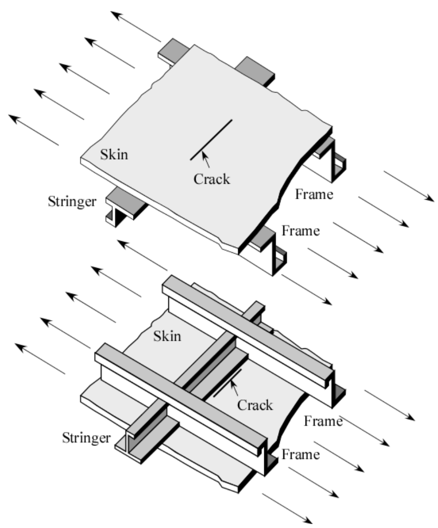

Fig.2: Typical model of a crack in a fuselage of an air craft panel.

Much research has focused on the behavior of composite panels. In this context, we can mention the work of Kadid. A [10] proposed a model to describe the behavior of composite panels stiffened but not cracked. In their research, Dexter et al [11] analyzed the crack growth effect on the behaviour of the long box girders with welded stiffeners. The model aims to assess the stress intensity factor based on the mechanical superposition of the linear-elastic fracture solutions, taking into account the typical motifs of residual stresses in the stiffened panels. The study of the effect of crack growth around the rivets in aluminum stiffened panels has been the subject of work provided by Toudeshky et al [12]. In this model, the finite element method is used to analyze the propagation of cracks in 3-D. In order to follow the fatigue crack growth in metallic flat panels stiffened by means of multilayered bonded pads, an experimental program and finite element analysis it was established by Boni et al [13]. In context to study the propagation of fracture behaviour of stiffened and unstiffened specimens subjected to lateral pressure, an experimental and FE analysis is presented by Željko et al [14]. In the model presented by Ming et al [15], the finite element method is used to investigate the residual ultimate strength of stiffened panels with locked cracks under axial compressive loading. In this study, the length and the crack orientation angle were considered. A probabilistic model analyzing the propagation of a crack affecting a stiffened panel is implemented by Feng et al [16]. To define the crack, the authors used the intensity factors by applying the finite element method.
As a continuity of the research mentioned above, we expect the proposal for an Ansys modeling for the study of the crack propagation in a composite panel. In addition, for reasons of reinforcement stiffeners can be placed to delay or stop the spread of this crack. The position, dimensions and loading the applied are the hand evaluated parameters for linear modeling of our composite laminate panel.

2. Problem definition Problem setting

To discuss the problem of crack propagation on the behavior of a composite panel, we analyze this various possible following configurations:

1- Panel Unstiffened.
2- Plate with only longitudinal stiffener.
3- Plate with only transverse stiffener.
4- Plate with transverse and longitudinal stiffeners.

The analysis of the fracture phenomenon focuses on the behaviour of the stress field in the crack tip region. The goal is to predict the best design to be used to optimize the behavior of composite panels in which a crack may occur

3. Modeling

The purpose of this work is to model a stiffened panel with a crack at its center. This panel is simply supported on its contour and exposed to a bi-directional loading. Because of the axial symmetry and the symmetry of the load, it was only considered the quarter panel. This technique allows reducing the grid and activating the calculation time. In order to block the propagation of this crack, two stiffeners are arranged in longitudinal and transverse direction. The panel is made completely of a composite graphite/epoxy with the mechanical characteristics data in Tables 1 and 2.

Table 1 : Mechanical properties of a composite Graphite Epoxy

E_1 (GPa)	E_2 (GPa)	E_3 (GPa)	G_{12} (GPa)	G_{13} (GPa)	G_{23} (GPa)	ν_{12}	ν_{13}	ν_{23}
130	10	10	4.85	4.85	3.62	0.31	0.31	0.52

Table 2 : Resistance of a graphite epoxy composite

X_T (MPa)	X_C (MPa)	Y_T (MPa)	Y_C (MPa)
1933	1051	51	141

E_1, E_2, E_3 : are longitudinal deformation moduli in the directions 1, 2 and 3.
G_{ij} : are the transverse deformation of modules. ν_{ij}: are the Poisson's ratios.
X_T : tensile strength in direction 1. X_C : compressive strength in direction 1.
Y_T : tensile strength in direction 2. Y_C : compressive strength in direction 2.

Our structure is modeled by ANSYS software. The proposed panel is six degrees of freedom at each node with a symmetrical lamination of eight layers [0/90/45/-45] of uniform thickness of 0.125mm. Figure 3 shows the mesh structure with the fastening methods and loading conditions.

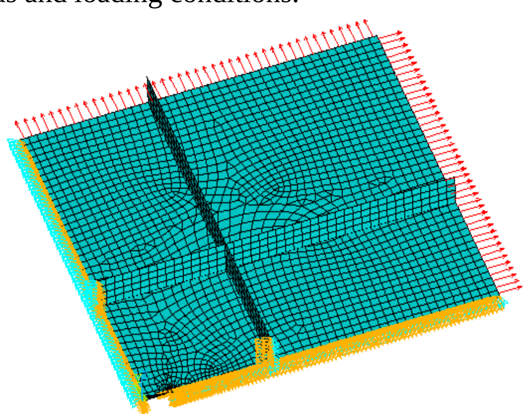

Fig. 3: Simply supported panel under a bi-axial tensile loading

ISSN : 2028-2508
CODEN: JMESC

4. Study parameters

Behavioral study the parameters of our panel, composite laminate, bidirectional cracked under tensile loading are:

3.1 *Effect of the intensity of the load*

To illustrate the evolution of the stresses along the panel and can follow the behavior as a function of applied load, was performed a gradual increase in the load of P=5 MPa at P=100 MPa. Thereafter, it traces the evolution of the longitudinal stress σ_x (Fig. 4), the transverse stress σ_y (Fig. 5) and the equivalent stress σ_{equi} (Fig. 6), along the panel for a progressive variation of the applied load. In all the figures, it is clear that the stress is always highest at the tip of the crack. The presence of the longitudinal and transverse stiffeners generates a fluctuating stresses. Moreover, the gradual increase of the load generates a sizeable increase in stress. For example, to equivalent stress (Figs 7 and 8), the maximum value at the point of crack password 39,605 MPa for a load P = 5 MPa to 792,103 MPa for a load P =100 MPa.

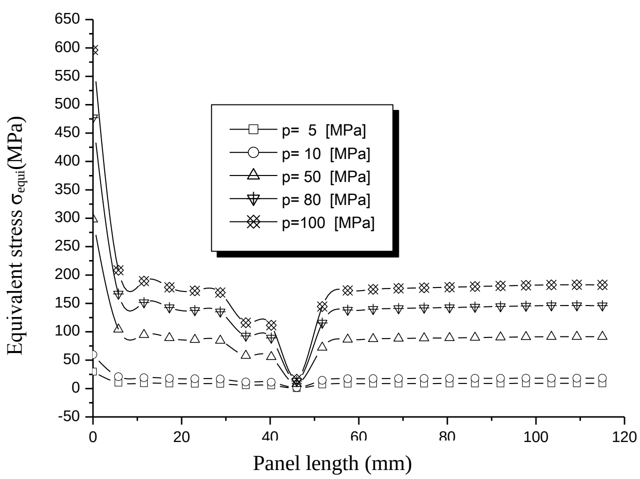

Fig. 4: Variation of the longitudinal strain as a function of load

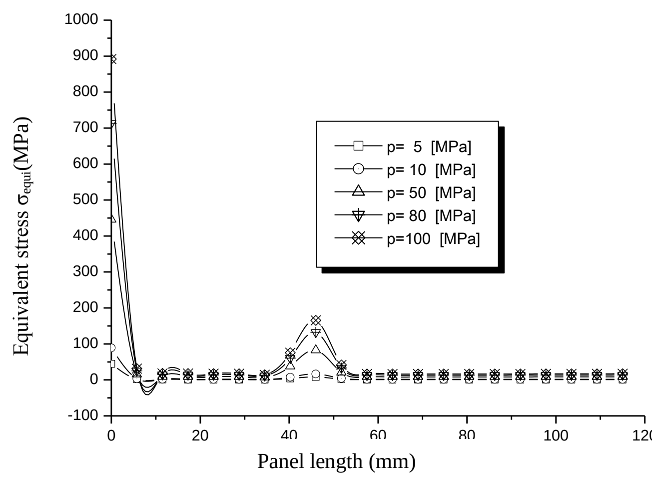

Fig. 5: Variation of the transverse stress as a function of load

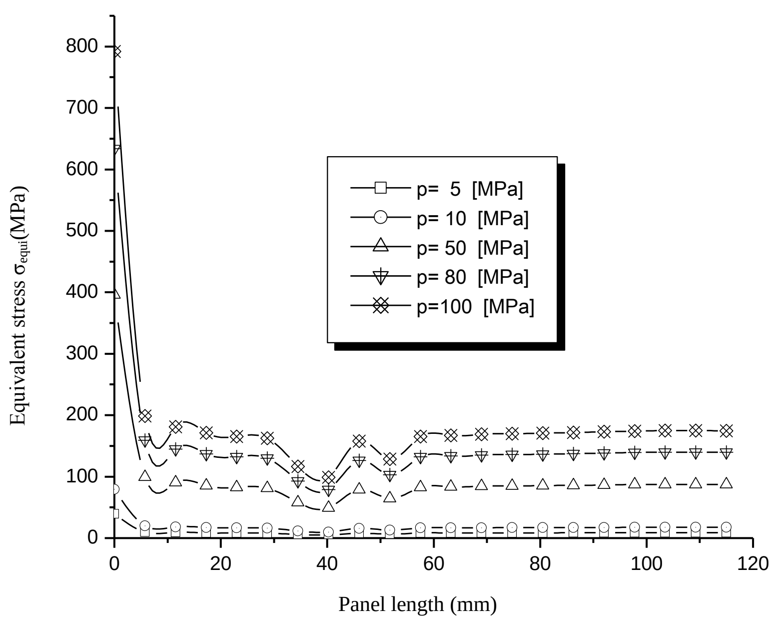

Fig. 6: Variation of the equivalent stress as a function of load

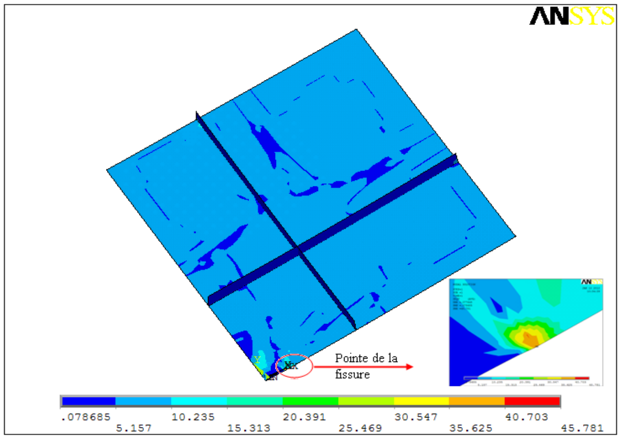

Fig. 7: Equivalent stress for a load P = 5 MPa

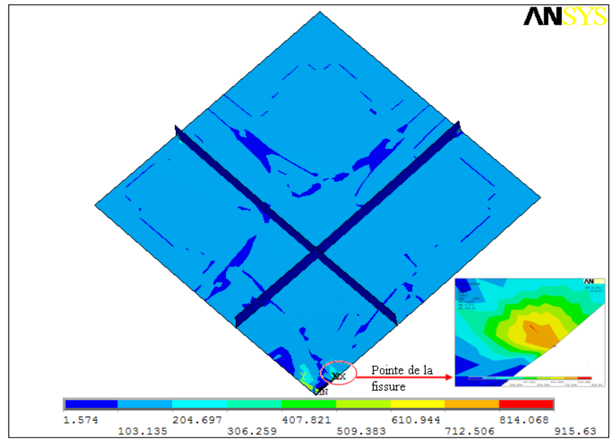

Fig. 8: Equivalent stress for a load P =100 MPa

3.2*Influence stiffeners*

3.2.1*Effect of the presence of stiffeners*

To test the effect of the presence of the stiffeners on the evolution of the equivalent stress at the crack tip, we have plotted in figure 9. This figure shows the change in the equivalent stress according to the increase of the load applied for four types of panels:

1- plate without stiffening
2- longitudinal stiffening
3- transversal stiffening
4- bidirectional stiffening

From this figure, it is clear that for low loads, the stiffeners have no effect on the evolution of this constraint. A superposition of the curves is observed up to a load of 10 MPa. Above this load, a clear distinction begins to appear between the four curves. For maximum load (P = 100 MPa), the location of the stiffening in the transverse direction allows a net reduction of this constraint, because it offers almost similar results to those of a stiffening in both directions. The worst case is that of a longitudinal stiffening because it hardly affects the equivalent stress; that is to say, the values are almost equal to those of a plate without stiffening. To better visualize this problem, there is shown the four figures 10 to 13 illustrate four cases of selected stiffening. It is obvious that for a load P = 100 MPa, the equivalent stress = 876 MPa for unstiffened plate (Fig. 10). This stress is reduced to 792 MPa if the stiffeners are placed in the transverse direction (Fig. 12).

Table 3 : Comparison between the equivalent stress and the weight of each panel

	Equivalent stress (MPa)				Total weightof the panel (Kg)			
Type panel	PUN	PLS	PTS	PTLS	PUN	PLS	PTS	PTLS
maximum value	876.01	863.21	798.86	792	0.08451	0.09113	0.09113	0.09788
Percentage added compared to PNR	0%	-1.46%	-8.81%	-9.59%	0%	+7.83%	+7.83%	+15.82%

PUN : Panel unstiffened. **PLS** : panel with longitudinal stiffener.

PTS : panel with transverse stiffener. **PTLS** : panel with transverse and longitudinal stiffeners.

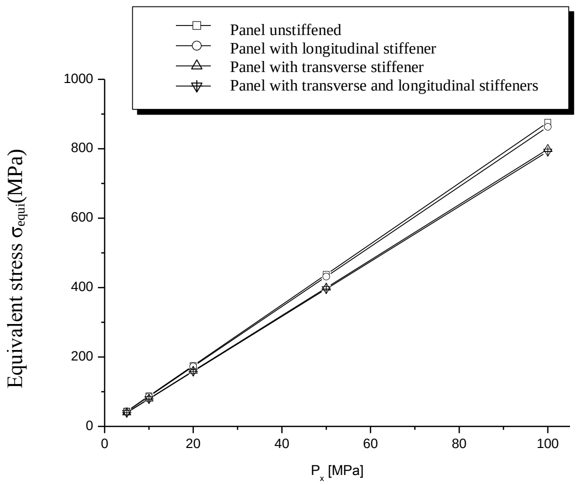

Fig. 9: Constraint equivalent to the crack tip for the four types of panels.

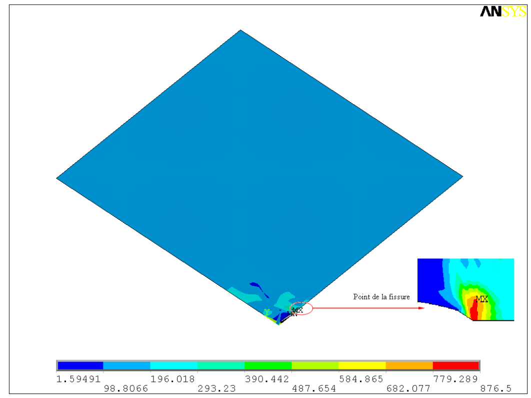

Fig. 10: Equivalent stress in a non-stiffened plate for P =100 MPa

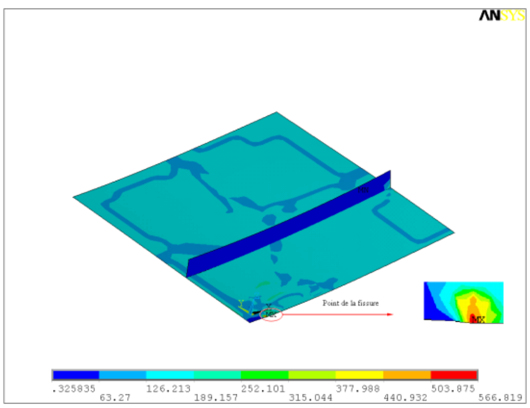

Fig. 11: Equivalent stress of a panel with longitudinal stiffening for P =100 MPa

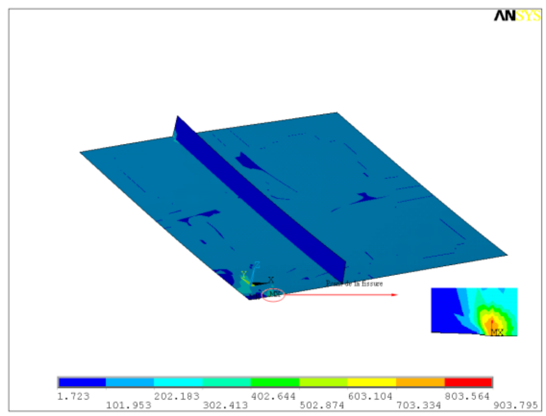

Fig. 12: Equivalent stress of a panel with cross stiffening for P =100 MPa

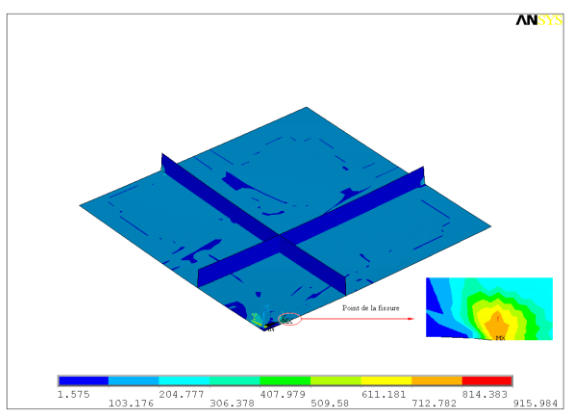

Fig. 13: Equivalent stress of a panel with bidirectional stiffening for P =100 MPa

ISSN : 2028-2508
CODEN: JMESC

3.2.2. *Influence of the position of the stiffeners*

To reduce stress concentration at the bottom of the crack and stop or delay the spread of the crack, it is essential to find an appropriate position of the stiffener. Therefore, the location of the stiffeners relative to the location of the crack is a determining factor for minimizing or stress relaxation at the bottom of the crack.

In this context, varying the transverse stiffeners position that the distances 0, 40, 80 and 120 mm from the end of the panel. Thereafter, is plotted in Figures 14 to 17 which show the distribution of this constraint. Of all of the figures, it is obvious that a high stress concentration is located at the crack tip (Figure 14). This stress concentration is less important with the approximation of the stiffeners to the tip of the crack.

To better visualize the evolution of this constraint, we plot in Figure 18. This figure represents the evolution of the equivalent stress according to the panel length for different positions transverse stiffeners. From this figure, we notice that the stress takes a peak at the bottom of the crack (maximum stress). Subsequently, it has an asymptotic value σ_{eq} = 50 081 MPa. The position of the stiffeners gives rise to fluctuations constraints (σ_{eq} = 409.52 MPa for a spacing of 40 mm, σ_{eq} = 396.05 MPa for a spacing of 80 mm and σ_{eq} = 431.23 MPa for the spacing of the end).

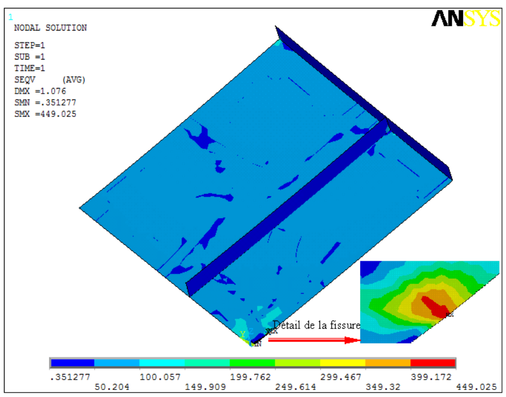

Fig. 14: Equivalent stress for a stiffener to the panel end

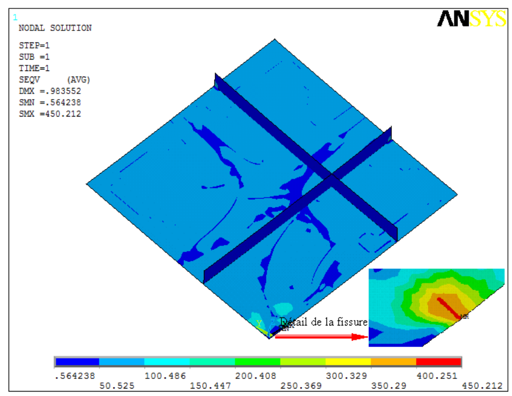

Fig. 15: Equivalent stress for a stiffener located 40 mm from the end of the panel

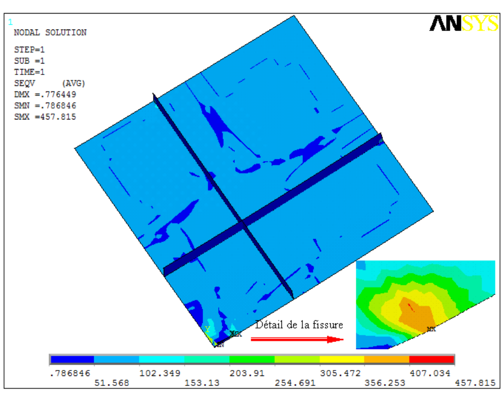

Fig. 16: Equivalent stress for a stiffener located 80 mm from the endof the panel.

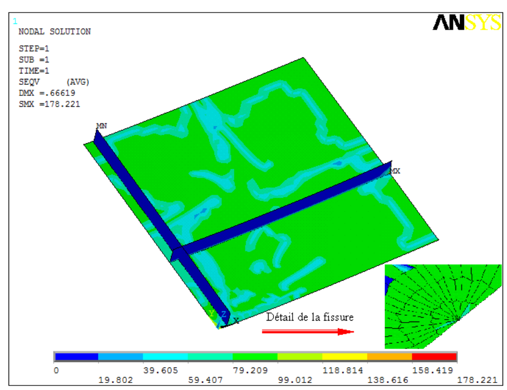

Fig. 17: Equivalent stress for a stiffener located 120 mm from the end of the panel.

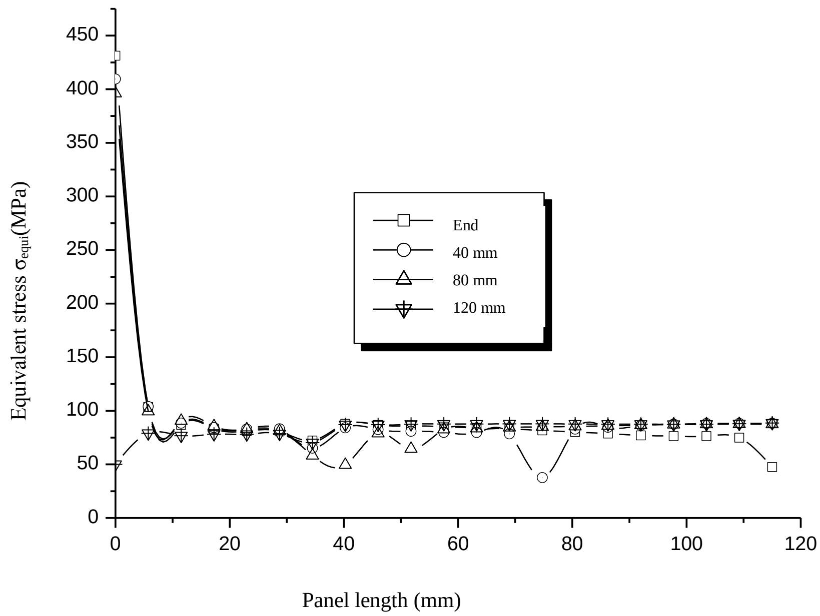

Fig. 18: Variation of the equivalent stress as a function of the position of The transverse stiffener under a load P= 50MPa.

3.2.3 *Influence of the thickness of stiffeners*

In order to relax the stress concentration at the crack tip, we will try to keep these constant times- it the position of the stiffeners, but their thickness varies only following the same stacking sequence data initially. The problem is therefore to double the thickness of each layer.

To clearly see the evolution of the stress concentration at the crack tip as a function of the thickness of stiffeners is shown in figure 19. From this figure, it is clear that increasing the thickness of the panel influences this constraint passing of 467.05 MPa for a thickness of 1.25 to 366.05 MPa for a thickness of 5 mm.

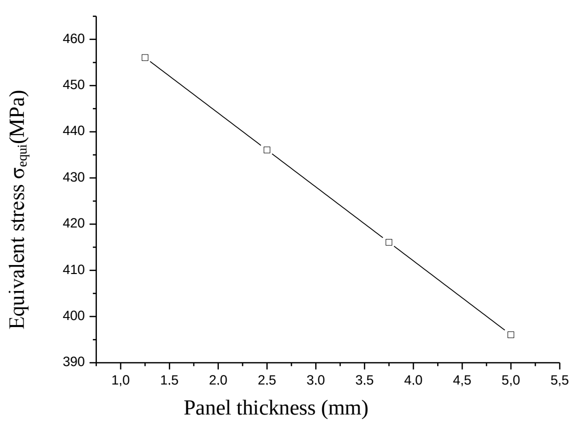

Fig. 19: Variation of the equivalent stress according to the variation of the thickness

3.3 *Influence of the orientation of the crack*

The variation in the position and thickness of the stiffeners are not the only parameters affecting this stress concentration. For this, is varied progressively panel tilt angle without changing the stacking sequences and applied loads. The entire mesh half panel with the loading and the fixing conditions are presented in figure 20.

Now we vary the angle of orientation of 0° to 90° in steps of 15°. Figures 21 to 27 illustrate the variation of the equivalent stress for angles of directions 0°, 15°, 30 °, 45 °, 60 °, 75 ° and 90 °. Of all of the figures, it is obvious that a high stress concentration is located at the tip of the crack.

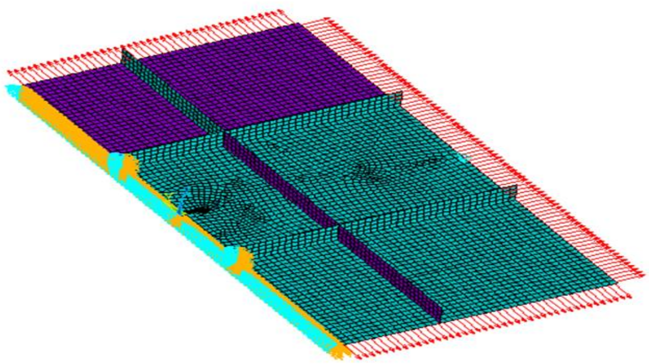

Fig. 20: The configuration of the analysed half-plate.

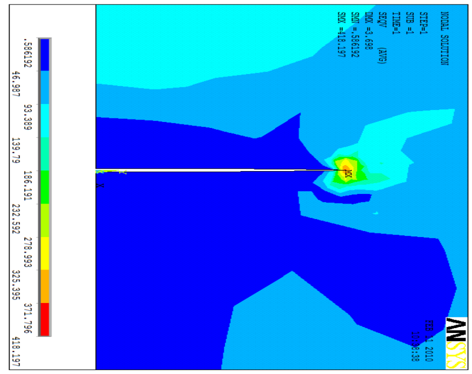

Fig. 21: Equivalent stress to 0 °

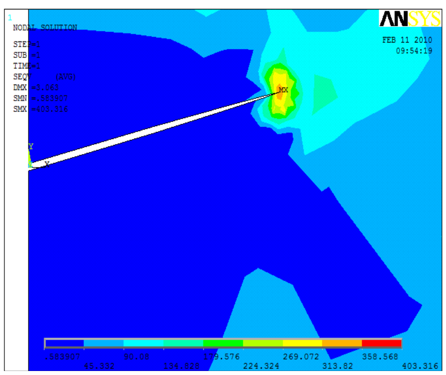

Fig. 22: Stress equivalent to 15 °

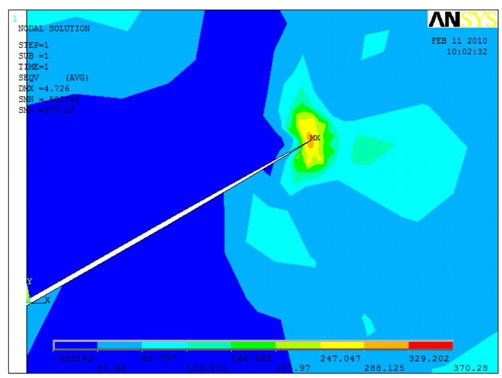

Fig. 23: Stress equivalent to 30 °

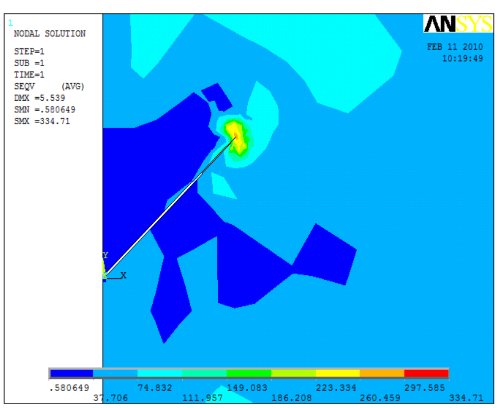

Fig. 24: Stress equivalent to 45 °

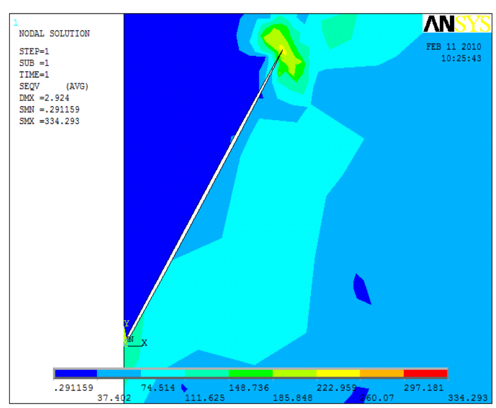

Fig. 25: Stress equivalent to 60 °

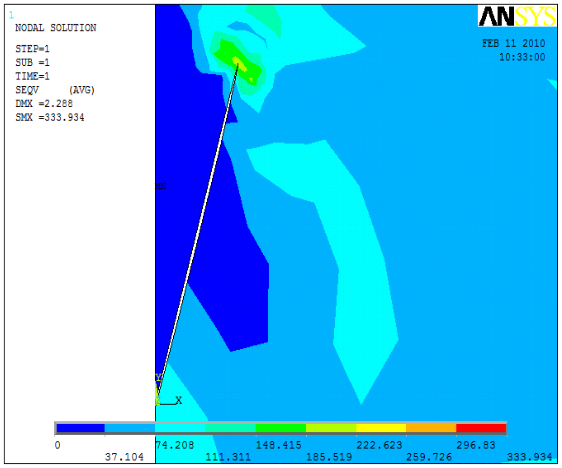

Fig. 26: Stress equivalent to 75 °

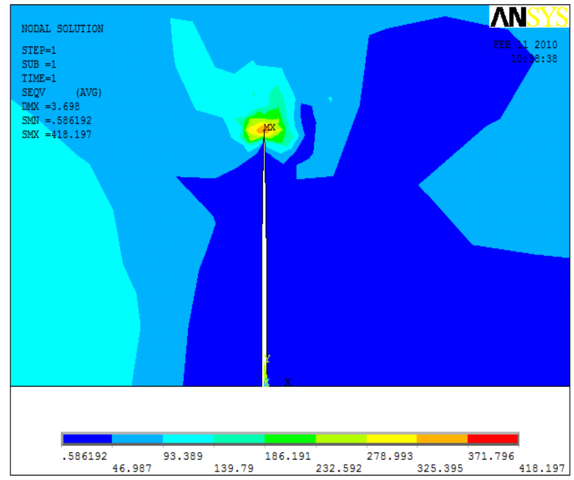

Fig. 27: Equivalent stress for 90 °

To better quantify this variation, we present the evolution of the equivalent stress at the crack tip based on the panel orientation angles. From this figure (Figure 28), it is evident that θ = 75 ° angle of orientation provides the minimum constraints against a direction of θ = 0 ° generates a high concentration of stresses. The therefore, it is desirable to carry out an orientation of 75 ° for better relaxation of stress concentration.

3.4 *Influence of material properties*
To check the effect of the nature of the materials on the stress concentration at the crack tip, four kinds of materials are proposed (IM6/epoxy, E-glass/epoxy, graphite/epoxy, Kevlar). To see the effect of the choice of materials, the figure 29 is a plot that illustrates the evolution of the equivalent stress along the panel. From this figure, it is clear that E-glass/epoxy material offers minimal constraints (σ=353.34 MPa). By cons, a Kevlar material produces a high concentration of stresses of 406 MPa.

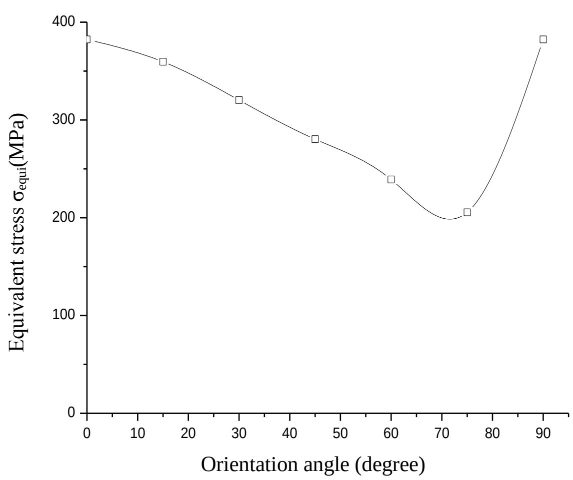

Fig. 28: Variation of the equivalent stress according to the inclination angle of the crack

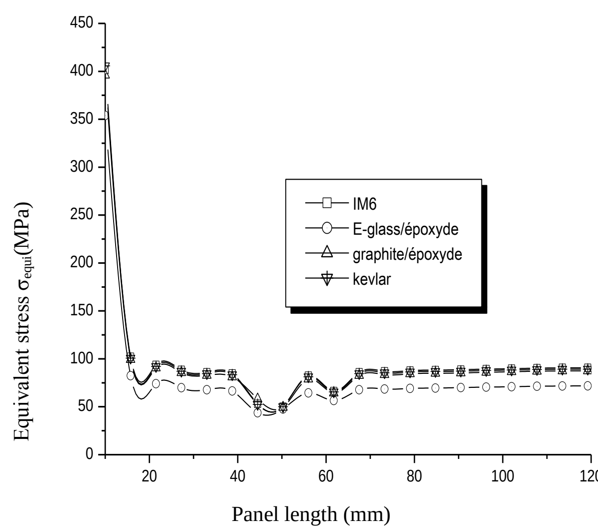

Fig. 29: Variation of the equivalent stress based on material properties.

Conclusion

For this work, the linear behavior of stiffened panels laminated composite having a longitudinal crack in bidirectional load was analyzed. The study was performed using ANSYS software, and provides a basis for the repair of laminated composite panels cracked after a possible shock. From the results, it turned out that for this type of panels, the crack propagation is related:

1- The nature of the load.
2- Fixing the conditions.
3- The geometry of the panel.
4- Orientation of the crack.
5- The type of materials.
6- The change in the equivalent stress is proportional to the applied load.
7- The maximum equivalent stress is always on the cutting edge of the crack.
8- The presence of the stiffeners creates slight fluctuation constraints.

The location of the stiffening in the transverse direction is more dominant because they:

- Contribute to blocking the propagation of the crack.
- Allow a significant reduction in weight compared to the stiffeners arranged in two directions.
- For loads of low intensity, the stiffeners have no effect on the behavior of our panel.

In order to minimize the stress concentration at the bottom of crack, stop and even delay the spread of the crack, it is recommended to place the transverse stiffeners in the vicinity of the tip of the crack.

Increasing the thickness of the stiffener has a considerable effect on the relaxation of the stress concentration at the crack tip, but in part against it gives an additional weight. In addition, it was observed that the stresses are significantly influenced by the fiber orientation angles.

For future recommendations include provision for patches for repairing cracked panels. In order to ensure structural stability, there is also address the buckling of panels and the stiffening sheet-peeling associated.

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