Identification of vibratory characteristics to the damage of a composite plate

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AbstractThe objective of this work is to study the damage behavior of composite structures by examining the influence on fatigue resistance. The finite element model of the plate will allow to analyze the vibratory behavior, to identify the stress, to study the influence of the dynamic loads on the natural frequencies of the plate in bending and torsion and will show the influence of the orientation of the Composite fiber macros on the rigidity of the plate and finally calculate the stability of the plate. The various damage mechanisms associated with these materials will also be presented with particular attention to delamination and cracking. This work will then focus on different technologies to improve the mechanical properties of these composite materials.

Keywords—material, crack, frequency, damage.

I. INTRODUCTION

Theconstant search for increasingly high performance in the aerospace field leads to the development of materials with specific rigidities and resistances increasingly high. In this new generation of materials, composites are trying to achieve a breakthrough.

Thus in aeronautics major global manufacturers have been able to make significant progress in developing cells and parts made of composite materials.

The use of new materials advantages are numerous, for example: they have an unlimited lifespan due to good fatigue strength, they are not susceptible to corrosion, they can be repaired easily, it is easier to level of production, etc.

All these benefits are responsive to the concern of aircraft manufacturers: performance and economy. In fact, the composite plates have offered compelling improvements over conventional weight saving solutionsbyLiang Huang [2015], reducing the cost of production and maintenance, extension of operational possibilities, improved performance while providing a security enhancement.

These new materials, all exhibit anisotropic behavior. In addition to achieve an efficient structure is necessary to achieve it with several materials by choosing the optimal directions for each axis orthotropic.

Synthesized research is conducted in order to take into account the crack propagation phenomenon fatigue in composite blades to assess the stability of the structure[Chellil et al. 2014].

The detection of the emergence and spread of structural damage is difficult. Nevertheless, a clear definition of the damage is not an easy task, for it Prashant and Ganguli [2005] we studied the feasibility of online fault detection for helicopter composite plates, damage modeled in the composite and the cracking of the matrix with stiffness and geometric properties similar to a composite plate.

The fracture processes induced depend upon the nature of the constituents, the architecture of the laminates and the type of mechanical loading imposed to the laminate.

Niranjan Roy [2005] studied the effect of the growth of damage on modal frequencies of the system and evaluated their feasibility for monitoring damage and fatigue life of the blade.

The effects of matrix cracking, peeling / delamination and fiber breakage on the structural properties of the response of the helicopter rotor are studied by Prashant [2005] in the case of forward flight. Firstly, the three major damage modes for a cracked matrix composite are determined based on the duality peeling / delamination, Mechakra et al [2015].

The aim is therefore, from a simulation of a model representative of the composite plate, develop predictive numerical criteria of the propagation of a crack in the plate.

II. ANALYTICAL FORMULATION

The description of themechanical behavior of acompositeplateis based onthe stress-strainrelationships designatedas theHooke's law. For the model ofthe stress-strainresponseof a plate, we use thegeneralized versionof the anisotropicbody.

Generallythese relationships haveallowedtwoexpressions;flexible andrigidascoefficients ofstress-strainrelations.Jones[1975]has provideda description of theserelations.The lawof the generalizedHookeconstraintsrelatedto deformationcan be writtenin theindex notationcontractedalso:

$$\sigma_i = C_{ij}\varepsilon_j \qquad i, j = 1,\ldots,6$$

Where σ_i straincomponents, C_{ij} isthe stiffness matrix, and ε_j isthedeformationcomponent. Componentsof rigidity andflexibilitiesoftendesignatedas theelasticconstants.The two sets ofcomponents mayberepresented byconstants

E_i, υ_{ij}, G_{ij} which arethe Young's modulus, Poisson's coefficientandthe shear modulus, respectively.
These constantsare especially usefulindescribing the behaviorofthelaminarlayer. New relationshipsreduced to21independent constantscan be representedby equations (1). These relationshipsrepresentan anisotropic materialbecause there is noplane of symmetry forthe material properties. This is the casewhere none of thebladeaxisisnotalignedwiththe principal axesofsymmetryof the material.

$$\begin{Bmatrix} \sigma_1 \\ \sigma_2 \\ \sigma_3 \\ \tau_{23} \\ \tau_{31} \\ \tau_{12} \end{Bmatrix} = \begin{bmatrix} C_{11} & C_{12} & C_{13} & C_{14} & C_{15} & C_{16} \\ C_{12} & C_{22} & C_{23} & C_{24} & C_{25} & C_{26} \\ C_{13} & C_{23} & C_{33} & C_{34} & C_{35} & C_{36} \\ C_{14} & C_{24} & C_{34} & C_{44} & C_{45} & C_{46} \\ C_{15} & C_{25} & C_{35} & C_{45} & C_{55} & C_{56} \\ C_{16} & C_{26} & C_{36} & C_{46} & C_{56} & C_{66} \end{bmatrix} \begin{Bmatrix} \varepsilon_1 \\ \varepsilon_2 \\ \varepsilon_3 \\ \gamma_{23} \\ \gamma_{31} \\ \gamma_{12} \end{Bmatrix} \quad (1)$$

The relationships stress-strainreduce toequation (2) inaplane of symmetry.These relationshipsare aplatein a coordinatesystemwhich rotatesin its plane,

$$\begin{Bmatrix} \sigma_1 \\ \sigma_2 \\ \sigma_3 \\ \tau_{23} \\ \tau_{31} \\ \tau_{12} \end{Bmatrix} = \begin{bmatrix} C_{11} & C_{12} & C_{13} & 0 & 0 & C_{16} \\ C_{12} & C_{22} & C_{23} & 0 & 0 & C_{26} \\ C_{13} & C_{23} & C_{33} & 0 & 0 & C_{36} \\ 0 & 0 & 0 & C_{44} & C_{45} & 0 \\ 0 & 0 & 0 & C_{45} & C_{55} & 0 \\ C_{16} & C_{26} & C_{36} & 0 & 0 & C_{66} \end{bmatrix} \begin{Bmatrix} \varepsilon_1 \\ \varepsilon_2 \\ \varepsilon_3 \\ \gamma_{23} \\ \gamma_{31} \\ \gamma_{12} \end{Bmatrix} \quad (2)$$

Forplane stressin the planeofthelaminarlayer, the equation (2)mayberewrittenwith respect tothecondensedstiffness matrix $[Q]$.
Placing σ_3, τ_{23} and τ_{31} equal zero,which implies that ε_3, γ_{23} and γ_{31} areequal to zero,leading to thefollowing ratio betweenthe components ofstressandstraincomponentsin the plan:

$$\begin{Bmatrix} \sigma_1 \\ \sigma_2 \\ \sigma_3 \end{Bmatrix} = \begin{bmatrix} Q_{11} & Q_{12} & 0 \\ Q_{12} & Q_{22} & 0 \\ 0 & 0 & Q_{66} \end{bmatrix} \begin{Bmatrix} \varepsilon_1 \\ \varepsilon_2 \\ \gamma_{12} \end{Bmatrix} \quad (3)$$

Where the elementsofthereduced-stiffnessmatrix[Q]are givenin terms of elementsofthe stiffness matrixinthreedimensions[C].
Equation (3)definesthestresses and strainsin the plane inthe system ofcoordinates of amajor hardwareorthotropicor transverselyisotropic material. Using theabove relationshipsin equation (3) allowsus to linkthe stresses in theplanedeformationintherotatedcoordinate systemasfollows:

$$\tilde{\sigma}' = \left[\overline{Q}\right] \tilde{\varepsilon}' \quad \text{ou} \quad \tilde{\varepsilon}' = \left[\overline{S}\right] \tilde{\sigma}' \quad (4)$$

Or

$$\left[\overline{Q}\right] = [T_1]^{-1}[Q][T_2] \quad (5)$$

And

$$\left[\overline{S}\right] = [T_2]^{-1}[S][T_1] \quad (6)$$

III. NUMERICAL STUDY FOR THE COMPOSITE PLATE

We use step module to create and configure analysis steps and associated output requests. The step sequence provides a convenient way to capture changes in a model.
In this work we study a helicopter fuselage made of glass / epoxy which have for properties:
E_1=36800MPaE_2=8270MPa $G_{1.2}$=4140MPa
ρ=2600Kg/m^3 μ=0.26
Where:E_1, E_2: two value of yong's module , ρ : Density
$G_{1.2}$= $G_{1.3}$= $G_{2.3}$: shears modules , μ: Poisson ration.

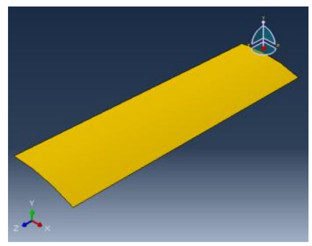

Fig.1. the property of martial with 2ply

The load module allows you to specify load, boundary conditions, and predefined fields. Loads and boundary conditions are step-dependent objects, which mean that you must specify the analysis steps in which they are active; some predefined fields are step-dependent, while others are applied only at the beginning of the analysis. And in our case we apply a force equal to F=100KN.
For the displacement we have:
U1=U2=U3=UR1=UR2=UR3=0
The mesh module contains tools that allow us to generate a finite element mesh on an assembly created within abaqus/CAE. The approximate global size equal to 10.

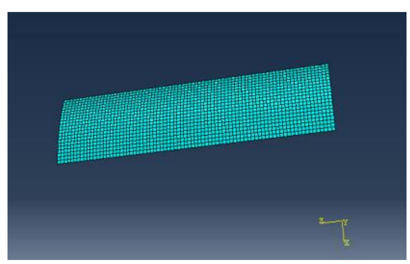

Fig.2. the composite plate

A. Simulation without crack

Modal analysis:

Mode 1:

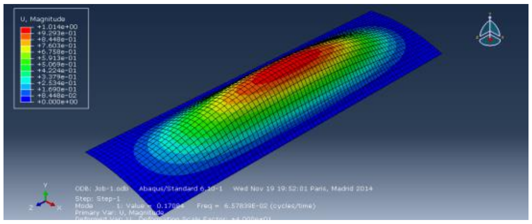

Fig.3. the first Mode shape
(U max=1.014 mm, f=0.657Hz)

Mode 2 :

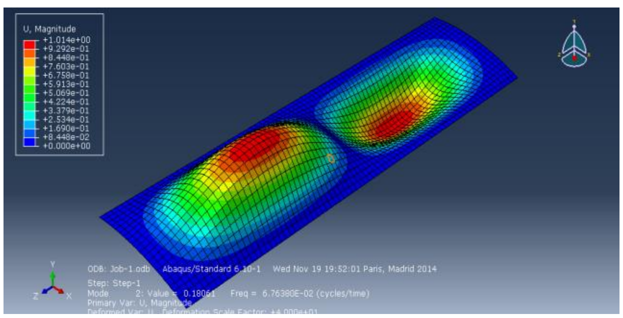

Fig. 4. the second Mode shape
(U max=1.014 mm, f=0.676Hz)

Von Misses Stress :

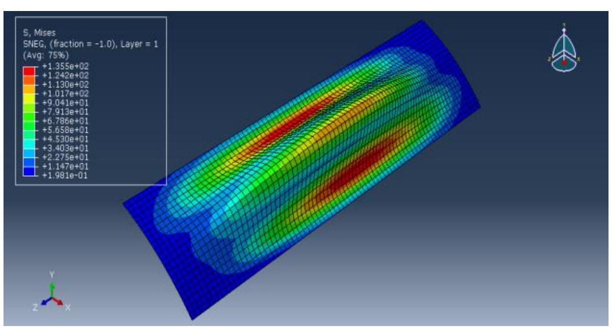

Fig.5. maximum stress of Von Misses
(Smax=1.35 e+02 MPa)

Figure 5 is observed that the critical load of the plate where the stress concentration is in the middle of the plate, and which is caused due to the critical loading. The value of maximum stress of 135 MPa.

Strain:

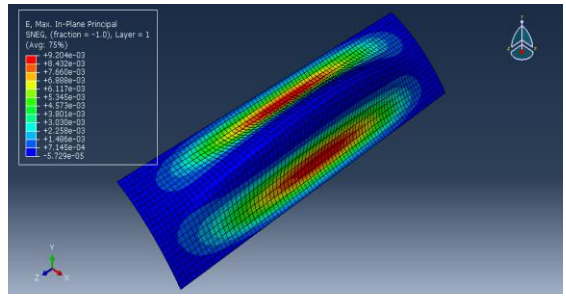

Fig.6. maximum strain (ε max= 0.920e-02)

*B. Simulation with crack*take a=10cm

Modal analysis

Mode 1:

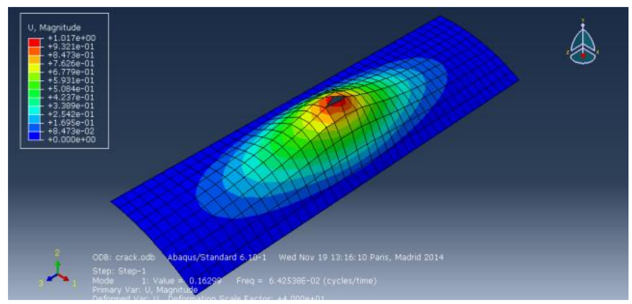

Fig.7. the first Mode shape
(U max==1.017 mm, f=0.642Hz)

Mode02 :

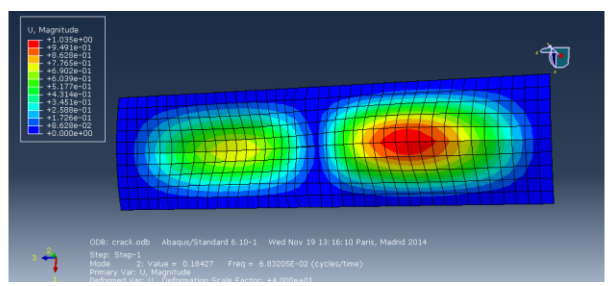

Fig.8. the second Mode shape
(U max==1.035 mm, f=0.683Hz)

Von Misses Stress :

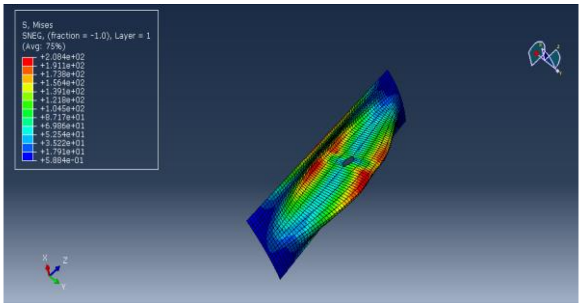

Fig.9. maximum stress of Von Misses (Smax=2.08 e+02 MPa)

There is a stress concentration at the edge of the crack. The strain value is σmax = 208 MPa; which can be interpreted by the appearance of a more sensitive area for the occurrence of damage.

Strain:

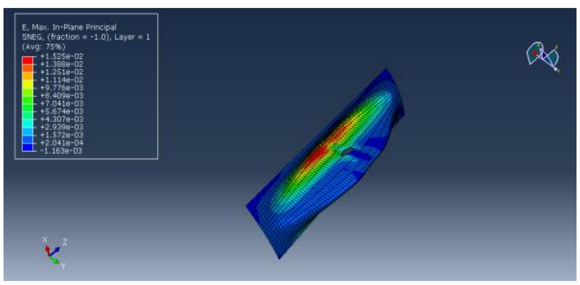

Fig.10. maximum strain(ε max==1.52e-02)

IV. Experimental study

Measurementhardware andinstruments(Fig. 11) is a 8801Instronmachine. this8801servohydraulicfatigue machinemeets the needs ofa wide variety offatigue testing. provides a completetest solutionfor testingof advanced materials.It is particularly suitablefor testingin low andhighnumber of cycles,witha capacityof up to 100kN, high stiffness, very accurate alignmentandwith characteristics.

• AxialCapacity±100 kN(22,500 lbf)
•inertia compensationforce sensor
• Standard orExtra HighOptionalBuilt
• Wide range ofgrips, fixturesand testaccessories

Fig.11. Materials testing

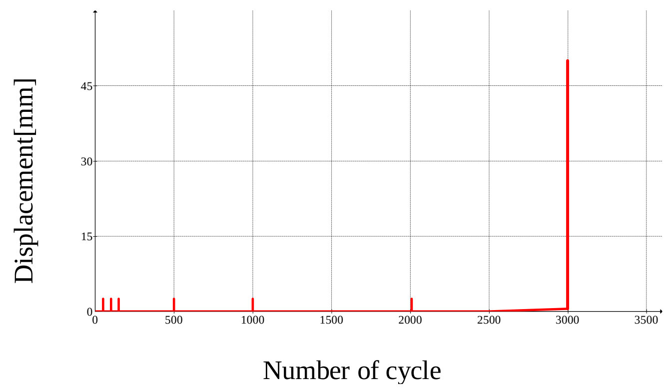

Fig.12. The displacement according the cycles number

From experience the fracture is occurring after 3010 life cycles, and so tenuously rupture occur (fast fracture). So the fracture in composites occurs rapidly.

V.Conclusion

The results obtained show that: the maximum displacements are in the middle of the plate. Von Mises stresses it possible to observe the critical areas, where it is necessary to determine the maximum load point of the plate and stress concentrations that are in the middle of the plate, due to high stress. Experimentally the fracture in composites occurs rapidly.
Also, modal analysis in terms of frequencies and modes may be employed as an indicator of the health of composite plates for predictive maintenance of the variable of the damage.

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