

Mechanical Behavior of Mode I Delamination of a Laminated Composite Material

Habib ACHACHE

IMSI University of Mohamed Ben Ahmed Oran2

Abdi GHEZAIL

Université Mohamed Benahamed Oran 2

Bouabdellah ABED

Université des Sciences et de la Technologie

Abdelouahab BENZERDJEB

Université des Sciences et de la Technologie

Abstract: The objective of our work is to analyze numerically in three dimensions by the finite element method of the effect of a mechanical load on the delamination of unidirectional and multidirectional stratified composites in order to determine the energy release rate G in Mode I and the Von Mises equivalent stress distribution along the damaged area under the influence of several parameters such as applied load and delamination size. The results obtained in this study show that unidirectional composite laminates have better mechanical strength on the loading line than multi-directional composite laminates.

Keywords: Delamination, Release energy rate, Stratified composite, Finite element method and ply

Introduction

Composite laminates are used in different sectors such as transportation (including aerospace and automotive). They are widely used in applications where weight reduction is essential. In addition, the use of a material is enlarged, the more the probability of a possible failure is increased. The ability to characterize failures, for example by identifying failure modes, characteristic parameters or critical failure values, is essential to ensure the integrity of parts and services when designing future products. The main aspect of this failure is the crack, which provides the location and progression of the fracture. The study of an existing crack and its stability is of great importance. In fact, the propagation of a crack can lead to the breakage of a component that can lead to the complete collapse of the structure. The fracture mechanics is the ideal tool to analyze this situation according to the breaking characteristics of the material, namely the critical stress intensity factor (K_c) and the critical energy release rate (G_c), also called tenacity. This composite degradation has been studied by several authors.

According to Bai, T and Pollard, D.D, Cracking, delamination crack tip and longitudinal or interlaminar cracking describe the different mechanisms of damage in transverse transversal laminates. The result of the spread and accumulation of these three types of damage causes the final collapse of the composite. The order and sequence of occurrence of such damage depends mainly on the following parameters: nature of the constituents of the fiber / matrix architecture of the laminated plate, fabrication process of the shaping and different types of charges.

In the literature, these damages have generally been studied separately: the studies concern either the propagation of cracks by an analytical or numerical method (Berthelot, J.-M. and Le Corre, J.-F), or on an analytical model delamination (Rebière, J.-L et al.). Haneeff, M et al. performed a finite element analysis to analyze the delamination effect on composite structures with two models. Smith B. W determined the angle of

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propagation of the crack; . A survey was again conducted by Todo, M., and Jar, PYB Using the Model and ENF (End Notched Flexure) Mode II (Todo, M., and Jar, Composite Fiberglass / Ester Composite) SEM). It was concluded that in mode II crack growth is a function of the properties of the fiber / matrix interface.

However, some authors have studied the role of transverse cracks in the initiation of inter-layer delamination as a function of properties. For example, Wang, J. and Karihaloo, B. L study the best stack (0° , 45° , 90°) to reduce the stress concentration at the bottom of the crack and the shear stress at the interface in mode II . Dasa, Subhankar et al. have studied the effect of overlap and winding on the reduction of the stress concentration at crack, which leads to suggest the propagation of cracks. He presented a finite element study of the micro-macro-mechanical growth of DCB fiberglass / interlaminar epoxy crack network samples for Mode I (Todo, M., and Jar, P. Y. B.). Because of the heterogeneity of the composite material, probabilistic studies have also been conducted according to two approaches: some Manders, P.W. et al. use a probabilistic criterion for the distribution of critical stress, while Katerelos, D.T.G et al. use a criterion of the random critical energy release rate. Szekrényes, András showed that shear stress at the interface contributes significantly only to the rate of energy release in mode II. Qing n, G.H et al. have located a semi-analytical model of energy release rate for delamination analysis of composites. Yao, Liaojun et al. used the energy deformation reimbursement rate for the characterization of fatigue delamination.

Our study is about the determination of the release energy rate G in mode I and the distribution of Von Mises equivalent stress along the damaged area. Different parameters were considered: - Effect of the applied loading. - Effect of the delamination size. The results show clearly better mechanical resistance on the loading line for the unidirectional stratified composites than for the multidirectional stratified composites.

Geometric Model

The composite laminate studied is a carbon/epoxy, it is composed of 20 plies, each with a thickness of 0.13 mm, with a symmetrical fiber; the first 8 plies are oriented at 0° and the other adjacent plies at 90° . Our analysis goal is to show the effect of several parameters such as the applied load and the delamination length on mode opening (model) for a test composite material with a length of 150 mm, width of 20 mm and a thickness of 2.6 mm.

The unsticking of layers was observed for a constant static load from 10 N to 60 N applied to the half-width of the specimen. For a distance of 5 mm, of his free end. The delamination is created according to the width of the composite material, and is located between the ten and the eleven layer of the stratified. The composite material is manufactured such as the initial length of the delamination area is 35 mm. The stratified composite material uses in this study is a carbon\epoxy, its mechanical characteristic are presented in table 1:

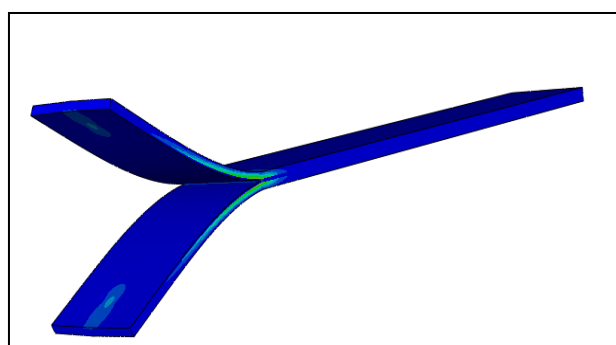


Fig. 1. Schematic representation of the geometrical model

Modeling

The adopted approach in this analysis is to use a reasonable modeling with a good refinement of the critical area [6]. In this digital analysis by the finite elements method, the specimen is modeled by quadrilaterals mesh elements of eight nodes, isoparametric type.

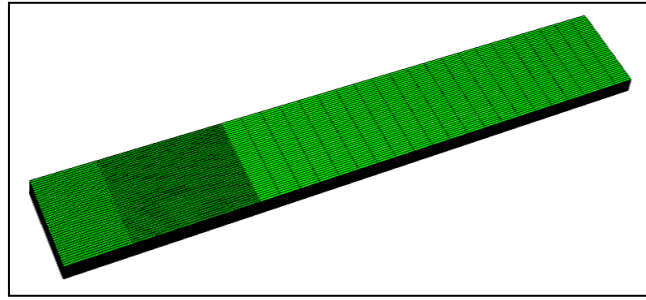


Fig. 2. Schematic representation of the geometrical model with modeling

Table 1. Orthotropic proprieties of unidirectional carbon/epoxy layer

Designation	Young's modulus E_{12} , MPa	Young's modulus E_{23} , MPa	Young's modulus E_{13} , MPa	Shear's modulus G_{12} , MPa	Shear's modulus G_{23} , MPa	Shear's modulus G_{13} , MPa	Poisson's ratio ν_{12}	Poisson's Ratio ν_{23}	Poisson's ratio ν_{31}
Carbon/epoxy	140000	10000	10000	5000	3850	5000	0.3	0.3	0.0214

Results

Effect of Applied Load

Case 1: Delamination Length of 35 mm

We represent, in Fig. 3, the variation of the equivalent release energy rate G in function off the length of delamination line (width of the specimen), for different load, we remark the increasing of G parameter with accretion of load. The minimal values of G parameter where observed in the free edge of the specimen, and begin to increase until a maximal value in the middle of his width. The style of the curve is almost a parabolic curve. For the low loads the release energy rate G is almost constant along the width of the specimen. The increasing rate of the failure parameter G is accented when in accordance with the applied load accretion

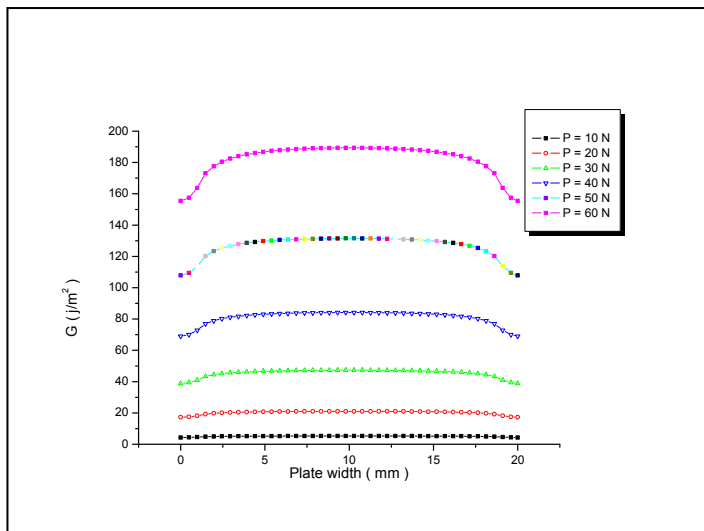


Fig.3. Energy release rate distribution versus plate width for delamination length of 35 mm

Case 2: Delamination Length of 45 mm

We observe the same behavior like the precedent figure, but in this time we remark that an increasing rate of G parameter most marked is as the one of the precedent case.

With the same load of 40 N; we remark that the maximum value of G parameter gives a rise of 77% as the precedent case.

- 20 N increasing of 70%
- 30 N increasing of 75%

The release energy rate G reached his critical value for applied loads breaking the 40 N barriers.

Case 3: Delamination Length of 55 mm

We registered an important increasing of the release energy rate G in relation to the precedent case, defined by s:

- 20 N increasing of 50%
- 30 N increasing of 53%
- 40 N increasing of 55%

The increasing rate of G parameter is more intense. Fig. 5 shows that for loads inferior of 40 N, there is no damage for the composite material.

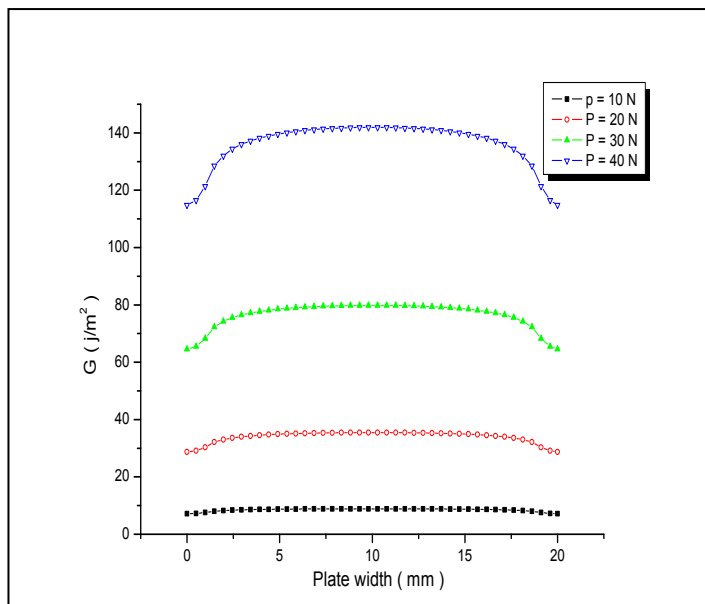


Fig.4. Energy release rate distribution versus plate width for delamination length of 45 mm

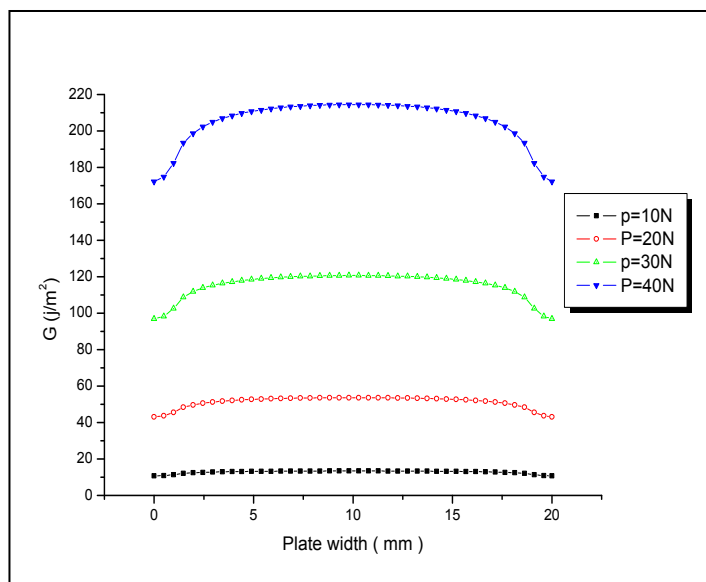


Fig.5. Energy release rate distribution versus plate width for delamination length of 55 mm

Case 4: Delamination Length of 65 mm

Fig. 6 shows that the length of delamination has a big influent on the G parameter. However, relatively to the length delamination of Fig. 5, this one present a significant values of G parameter with those percentages:

- 20 N increasing of 35%
- 30 N increasing of 39%

Fig. 7 shows the variation of G equivalent for the two positions P_1 and P_2 . The difference between the two values of G parameter are due principally to the increasing of applied load, and reach his maximal value for a delamination length of 65 mm.

Comparatively to Fig.3, we mark an important difference of G equivalent for the two positions P_1 and P_2 for a load near of an average equal to 20 N. this difference increase with the accretion of load, and it reach the 16% for a load of 30 N, for wish the G parameter approach the critical value in the position P_2 .

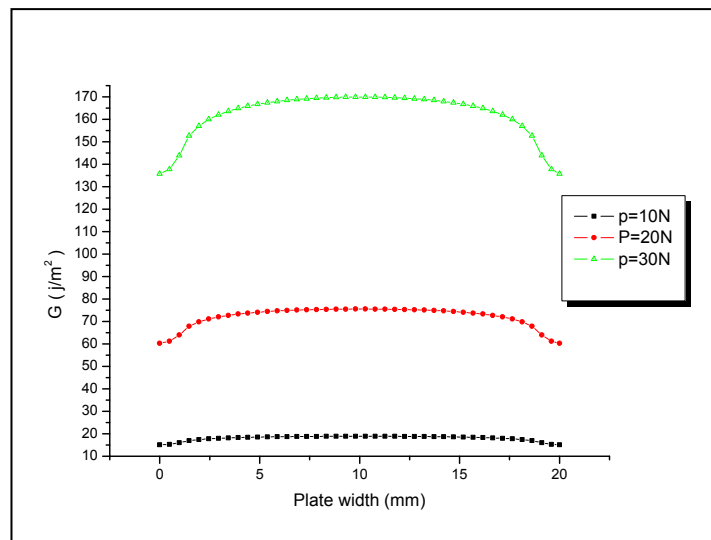


Fig.6. Energy release rate distribution versus plate width for delamination length of 65 mm

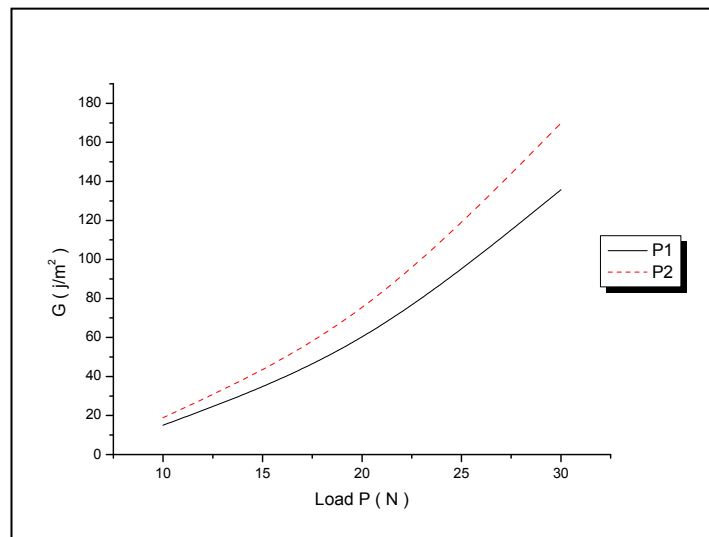


Fig.7. Evolution of G parameter with applied loads for the two positions P_1 and P_2

Comparison between the Unidirectional and Multidirectional Stratified

Fig. 8 represents the distribution of release energy rate G in function with the applied loads for a unidirectional stratified composite with a delamination length of 35 mm. We remark from a part, that whatever the stratified composite material, the release energy rate G proportionally varied with the applied load, other part, from the digital results obtained, we observe that the multidirectional stratified composite (Fig. 3), present a most marked

level of release energy rate G equivalent as the unidirectional stratified composite. This attenuation of G parameter is due principally to the mechanical resistance of unidirectional fibers on opened mode in the delamination area.

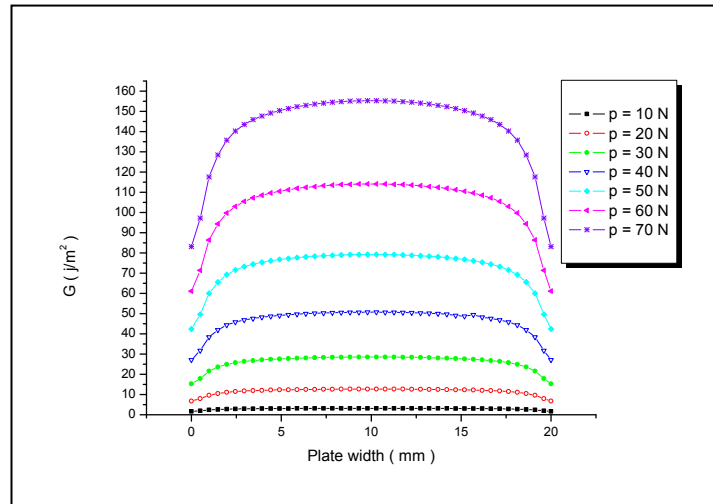


Fig. 8. Energy release rate distribution versus plate width for delamination length of 35 mm

Stress Distribution

We represent the variation of Von Mises stress equivalent intensity and distribution on the requested zone defined by the both position P_1 and P_2 . We recall that the mesh was refined at the level of this zone to obtain accurate results. The stresses are determined in the various layers of the laminated composite according to the inter distance going from the undamaged zone to the one where the load is applied.

Through the line of delamination, whatever the two positions P_1 and P_2 , the stresses growing in from the undamaged area, reaching a maximum value at the delaminated line and decrease proportionally away from the latter, towards the point of load application.

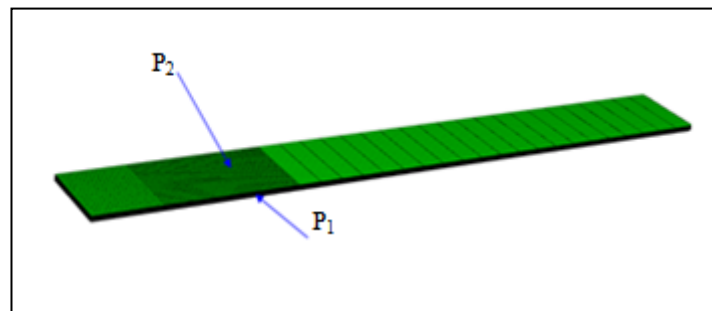


Fig. 9. Mesh model and representation of the positions P_1 and P_2

Position P_1

Laminated Unidirectional

We observe that the stress field is localized at the level of the line gouged (between ply 10 and its symmetrical, ply 11) for the composite unidirectional. The stresses decrease as we go further from the defect where the stresses are concentrated.

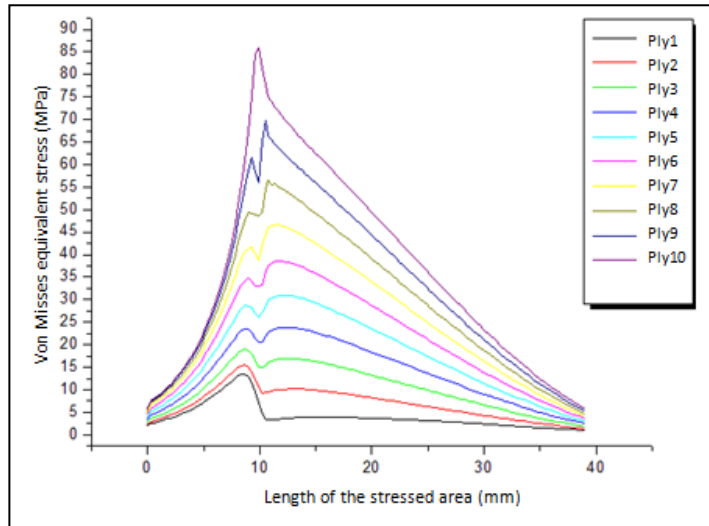


Fig. 10. Distribution of G versus platewidth for P₁ position (UL)

Cross Laminated

There is a considerable fall of the stress field at the level of ply 9 and 10 oriented to 90° and constraints in the other folds are more intense than those of the composite laminate one-way. The plies9 and 10 oriented 90° have a low resistance to the opening of the composite and therefore constraints are transferred to the other folds facing 0°.

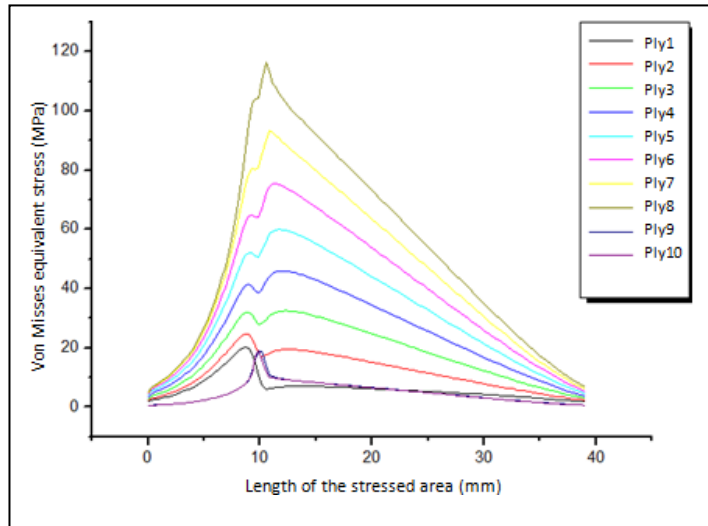


Fig. 11. Distribution of G versus plate width for the P₁ position(CL)

Conclusions

This numerical study, can draw the following conclusions:

- The delamination of composite laminate in mode I depends on the intensity of the applied load and the surface of the damaged area.
- The rate of refund of energy values are maximum in the middle of the width of the plate composite laminate and they are minimum two free ends of the laminated composite material, specifically at the level of the line of delamination.
- Compared to the cross laminatecomposite, composite unidirectional presents a good mechanical strength, because oriented at 0° ply better resist the imposed load those oriented at 90°.
- Under the effect of the same loading type and the presence of an identical defect, it is noted that the high level of the equivalent von Mises stress of the cross laminate composite in the ply close to the defect is due to the transfers of constraints following the non-solicitation of adjacent fibers that are oriented at 90 ° and

that have a low von Mises equivalent stress; but that of the unidirectional composite increases gradually from the first ply to the one that is at the closest vicinity of the delamination line.

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Author Information

Habib Achache

University of Sciences and Technology M. B. Oran
Boite Postale 1505 El Menouar Oran, Algeria
Contact E-mail: abdoubenzerdjeb@yahoo.com

Abdi Ghezail

Industrial Maintenance and Safety Institute , University
Oran 2 Name of Institution or University 170 bp 170 EL
Mnawer, Oran, Algéria

Bouabdellah Abed

University of Sciences and Technology M. B. Oran
Boite Postale 1505 El Menouar Oran, Algeria

Abdelouahab Benzerdjeb

University of Sciences and Technology M. B. Oran
Boite Postale 1505 El Menouar Oran, Algeria
