Analysis of the Free Edge Effect of a Composite Laminate under Axial Tensile Load According to the Environmental Properties of the Composite Materials

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Abstract

In recent years, composites have been used to reduce the overall weight of the structure and reduce the consumption of fossil fuels in aircraft due to their light weight property. The purpose of this study is to investigate the interlayer stresses created in composite layers due to the effect of free edges. In fact, in this study, the distribution of stresses affected by free edges (interlayer stresses) that create force and torque in the direction of thickness is investigated. For this purpose, the changes of the mentioned stresses with the help of numerical modeling for multilayer composite by finite element method are investigated by Abacus software and the environmental effects of composite materials are also discussed. Finally, the effect of different layers on this phenomenon in terms of thickness and width of several composite layers under axial tensile load will be investigated. As a result, on one hand the extended usage of green materials like composites can potentially reduce the previous heavy metallic structures which use more fuel and have much more environmental side effects, and on another hand some stress analytical results such as symmetrically distribution of σ_{zz}, asymmetrically distribution of τ_{yz} across the width of multilayer and other discoveries for angle-ply and quasi-isotropic multilayers due to the effect of free edge are gained.

Keywords: Free Edge Effect, Interlayer Tension, Laminate Composite, Finite Element Method.

1. Introduction

Today, engineering science has advanced in various fields such as automotive, aerospace, construction and biomechanics, and composites have replaced metals in many industries [1,2]. Modern aircraft wings can be designed from different types of materials, depending on the structural function. The wing of an aircraft is comprised of different parts, such as skin, spar, and ribs, flight control surfaces, like ailerons and flaps. Each of these parts is supported by different loads and, thus, the right material must be selected. Several factors influence the selection of material, of which strength allied to lightness is the most important [3]. Composite materials are widely used in aerospace and mechanical engineering due to their desirable mechanical properties. The effects of free edges are one of the topics studied in composites and one of the main causes of damage in composite multilayers is the interlayer stresses. Even when the stresses between layers are much less than the failure strength of the classical theory of layers, they can play a significant role in separation. These stresses may lead to the composite not being able to withstand the load capacity due to delamination. In the vicinity of the free edges, the stresses between the layers change very quickly, which is the main reason for the delamination. Delamination of multilayer composite sheets is the most common form of damage in composites [4]. The importance of this issue is such that this phenomenon in itself can cause damage to structures.

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To the extent that sometimes, in some laminates, this effect reduces the load-bearing capacity of the multilayer by about one hundred percent. In orthotropic materials, layers have different properties and off-plane single stresses may occur even under in-plane tensile loads [5]. In fact, the stress state is near the three-dimensional free edges. Interlayer stresses have one normal interlayer stress component and two shear stress components , .In fact, it should be noted that although these stresses are called interlayer stresses, they are not limited to the stress between two layers within the plate and can have normal stresses. Since the stresses at the free edges are not in the plane stress state, the classical multilayer theory will not apply in this area. Farther from the edges, the stress state returns to the plane stress, and the classical theory of layering will prevail in those areas [6]. Examination of the model equilibrium can justify the existence of interlayer stresses in a multilayer composite with free edges. In other words, according to elastic theory, the plane stress state is restored in areas far from the free edges, so the equilibrium of a single layer (or group of layers) requires the existence of normal shear stresses between layers [7]. The integral of these stresses on their applied regions causes forces and moments that must be in equilibrium with the calculated forces and moments. Therefore, it is very important to study the stresses between layers in practical applications, which researchers have done a lot in this regard. Recognizing this phenomenon and accurate modeling of it is a prelude to more accurate analysis and design of composite structures.

The aim of the present study is to investigate the interlayer stresses due to the effects of free edges.
For this purpose, the effects of different layers on this phenomenon in terms of thickness and width of the composite multilayer under axial tensile load will be investigated.

2. Materials and Methods

As an initial introduction to the problem, a qualitative study of how the two layers of zero degrees and 90 degrees adjacent are deformed. Due to the difference in Poisson's ratio between these two layers compared to the defined axes according to the Fig. 1. and also assuming that the layers are not attached to each other, the zero-degree layer has less change in length in the X direction and more width change in the Y direction. In contrast, the 90-degree layer has a greater change in length in the X direction and a smaller change in width in the Y direction. As a result of this deformation difference between the two layers, off-plane shear stresses occur.

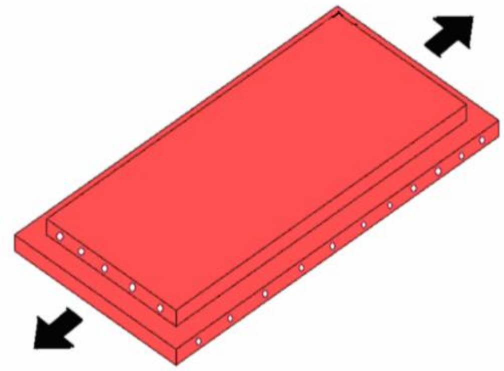

Fig. 1. How to deform two adjacent layers of zero degrees and 90 degrees.

The balance of the two adjacent layers is now being examined. Due to the formation of the two layers, the zero-degree layer will be under tension and the 90-degree layer will be under pressure. The section in Fig. 2. has a balance in the Y direction. But the equilibrium around point A indicates that there is a need for tension in the Z direction to establish it.
Therefore, at the end edge, there should be stress according to Fig. 3. to balance around point A. On the other hand, the presence of stress requires that the equilibrium be in the z direction, and since there is no balancing force in this direction, it is necessary that the integral of the stress on this edge be zero.
The zero-degree layer equilibrium is now being examined.
According to Fig. 4., the equilibrium in the Y direction requires that the shear stress exists at the contact surface between the zero and 90 degree layers. On the other hand, equilibrium around point A requires that the stress be present at the end edge.

On the other hand, equilibrium in the z direction requires that the integral of stress on the interface of the two layers be zero.

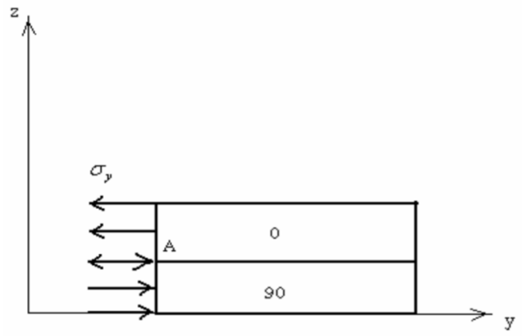

Fig. 2. Equilibrium of forces of two-layer of zero degrees and 90 degrees adjacent.

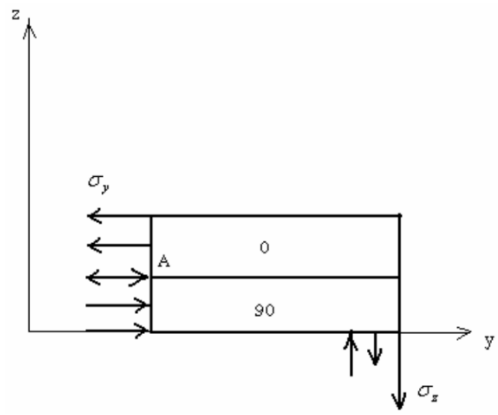

Fig. 3. Equilibrium of moments of two layers of zero degrees and 90 degrees adjacent.

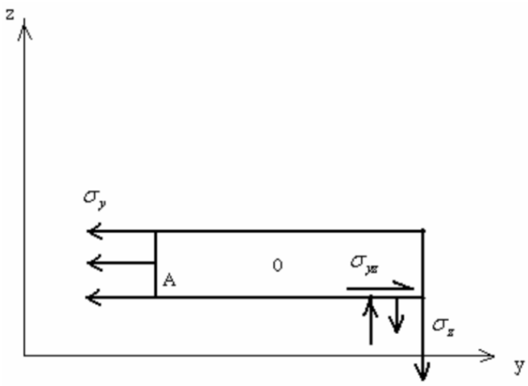

Fig. 4. Zero-degree layer force and moment balance.

in plane loading , and in plane stresses and symmetric layup, and are induced in the interior laminates of specimens. Near the free edge, plane stresses , and are called interlaminar stresses induce. These stresses are for balancing in plane stresses near free edges. Fig. 5. depicts an element near the free edge of a composite laminate.

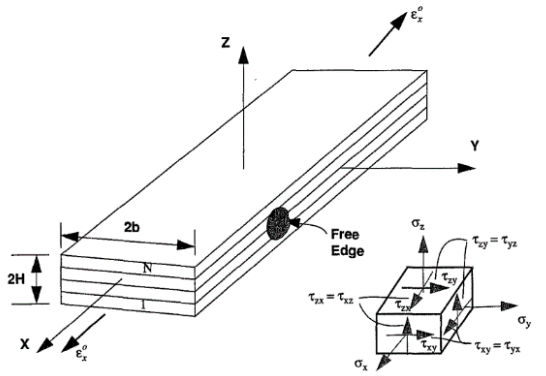

Fig. 5. stress distribution in one element near free edge [6].

The specimen is loaded by an axial force N_x by stretching along x direction. For a balanced, symmetric laminate the mid-plane strains and curvatures are uniform over the entire cross section and given by bellow formulas in which $\alpha_{11} and\, \alpha_{12}$ are in plane laminate compliances [6].

$$\varepsilon_x^0 = \alpha_{11} N_x$$

$$\varepsilon_y^0 = \alpha_{12} N_y$$

$$y_{xy}^0 = 0$$

$$kx = ky = kxy = 0 \qquad \text{Eq. (1).}$$

A lamina subjected to tensile loading in one direction will contract in the direction perpendicular to the load. If two or more layers with different Poisson's ratios are bonded together, inter laminar stress will be induced to force all layers to deform equally at the interfaces (Fig. 6.) [4]. Over the entire laminate thickness, these stresses add up to zero since there is no transverse loading N_y applied. In other words, they are self-equilibrating in such a way that

$$\int_{Z_0}^{Z_x} \sigma_y dz = 0 \qquad \text{Eq. (2).}$$

Where z_0 and Z_n are the coordinates of the bottom and top surfaces. The in-plane stress δ_y calculated with classical lamination theory is self-equilibrating when added through the whole thickness, but on a portion of the laminate (above Z_k in Fig. 2.), the stresses σ_y may not be self-equilibrating. Therefore, the contraction or expansion of one or more layers must be equilibrated by inter laminar shear stress τ_{yz}. Since there is no shear loading on the laminate, the integral of τ_{yz} over the entire width of the sample must vanish.

The free body diagram of sub laminate which discussed is shown in Fig. 6. However, an inter laminar shear force exists if the stress σ_y above or below the surface is not self-equilibrating.

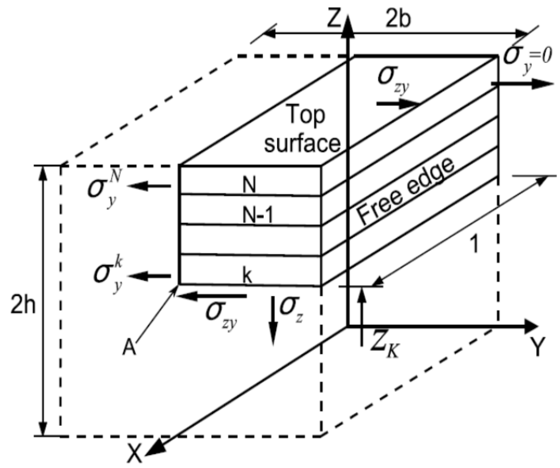

Fig. 6. free body diagram of sub laminate used for computation of Poisson-induced forces [4].

The inter laminar shear stress τ_{yz} is not available from classical lamination theory but the transverse stress σ_y is. Therefore, the magnitude of the inter laminar shear force can be computed anywhere through the thickness of a laminate in terms of the known transverse stress distribution σ_y [7].

The in-plane stress σ_y in a balanced, symmetric laminate under tensile load is constant in each lamina. Therefore, when the inter laminar force is evaluated at an interface (located at z = z_k), the integration above reduces to:

$$F_{yz} = (-Z_k) = -\sum_{i=k}^{N} \sigma_y^i t_i \qquad \text{Eq. (3).}$$

Where t_i are the thicknesses of the laminas. F_{yz} is the magnitude of force per unit of length. Not self-equilibrating distribution of stress yields both force F_{yz} and moment [8].

To compute the moment M_z, take moments of the stress σ_y with respect to an arbitrary point of section. The M_z leads to create σ_z

$$M_z(z_k) = \int_0^b \sigma_{z(z=z_k)} y dy = \int_{z_k}^{z_N} \sigma_y (z - z_k) dz \text{ Eq.(4).}$$

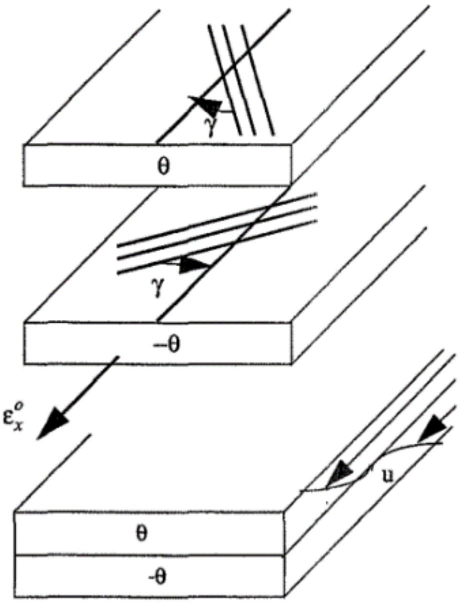

Fig. 7. deformation caused by mutual influence [6].

In classical lamination theory, it is assumed that the portion of the laminate being analyzed is far from the edges of the laminate. Stress resultants N and M are then applied to a portion of the laminate and these induce in-plane stress σ_x, σ_y, τ_{xy} on each lamina. In the interior of the laminate, inter laminar stress τ_{xz}, τ_{yz} are induced only if shear forces are applied.Off-axis laminas induce in-plane shear stress when subject to axial loading because the natural shear deformations that would occur on an isolated lamina are constrained by the other laminas which illustrates in Fig. 7. [6]. through the whole thickness of the laminate, these stresses cancel out, but over unbalanced sublaminates, they amount shear. That shear can only be balanced by inter laminar stress σ_{zx} at the bottom of the Sublaminate:

$$F_{xz}(z_k) = \int_0^b \sigma_{xz(z=z_k)} dy = -\int_{z_k}^{z_N} \sigma_{xy} dz \qquad \text{Eq. (5).}$$

As shown in Fig. 8., the presence of σ_y and τ_{xy} stresses between the composite layers, due to the mismatch of the Poisson ratio of the layers, disturbs the self-equilibrium of the structure, causing interlayer shear stresses. The shear stresses created according to the type of layup, to satisfy the self-equilibrium conditions, may create normal interlayer stresses. Although σ_y and τ_{xy} stresses can be calculated from the classical theory of laminates, this theory is not able to study interlayer stresses. As a result, by considering an arbitrary element for the thickness of the multilayer and rewriting the equations of static equilibrium in the presence of interlayer stresses, their values are calculated.

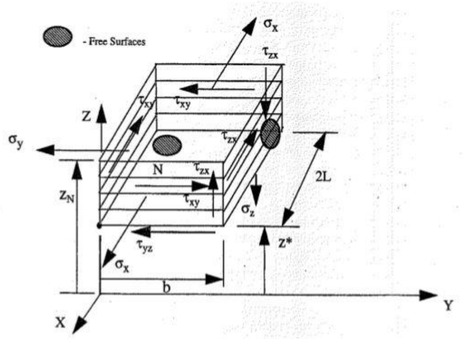

Fig. 8. Free diagram of a composite multilayer in the presence of free edges [6].

Accordingly, the interlayer stresses σ_z and τ_{yz} due to the presence of σ_y cause the parameters M_z and F_{yz}. Also, the shear stress τ_{xz} occurs between the layers, which is the parameter F_{xz} resulting from this stress.
The values of F_{yz}, F_{xz} and M_z can be calculated according to below equations [10].

$$F_{yz}(z^*) = \int_0^b \tau_{yz}(z^*) dy = -\int_{z^*}^{z_N} \sigma_y dz$$

$$F_{zx}(z^*) = \int_0^b \tau_{zx}(z^*) dy = -\int_{z^*}^{z_N} \tau_{xy} dz$$

$$M_z(z^*) = \int_0^b \sigma_y(z^*) dy = \int_{z^*}^{z} \sigma_y (z - z^*) dz$$

3. Modeling and Results

In order to model the composite layers in Abaqus, finite element software, the dimensions were considered as shown in Fig. 9.

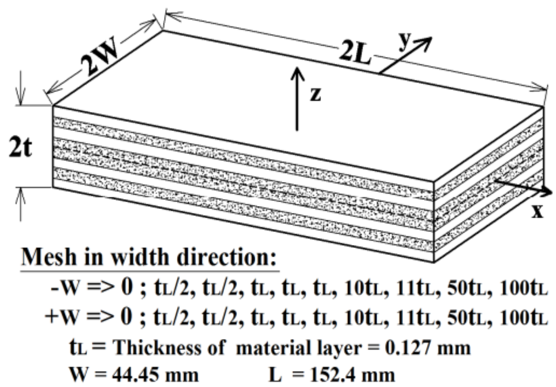

Fig. 9. The geometry of model.

Meshing should be done in such a way that it shows the interlayer stresses as well as possible. For this purpose, to better control the stress gradient in each element, it is necessary to use high-order elements.

The elements used in the present study are selected from the function of the order of two-order shapes and from the hexagonal family of twenty-node (C3D20). In order to element the composite, it should be noted that as the joint boundary of the layers or free edges approaches, the elements should become smaller, but in the longitudinal direction of the composite (x), this is not necessary.

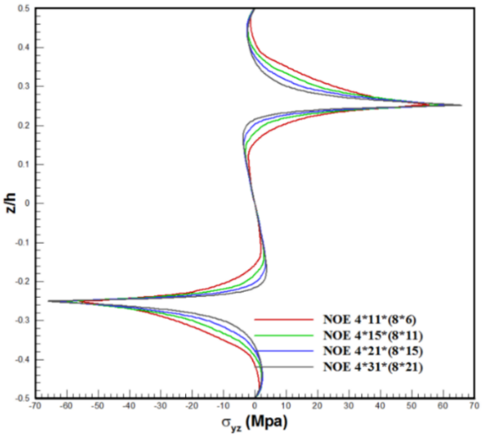

Fig. 10. Meshing effect.

Fig. 10. compare the results with increased mesh. For example, NO 4*11*(8*6) means we have 4 elements in length and 11 elements in width and 6 elements per ply. The black plot in Fig. 10. is effective and smooth meshing, but because of limited computer time, we use the above-explained procedure of meshing and, according to Fig. 10., we can get acceptable results. The variation of stress near the free edges is severe, so we consider this issue by fragment of size and increasing the number of elements near the free edges. For this purpose, on the longitudinal lines there are 6 elements with equal distances as shown in Fig. 11. (in order to better investigate the results at a point far from the area of Saint Venant), in the direction of the width, there are14 elements by shrinking the element from the middle to both sides, and in the direction of the thickness each ply in this modeling has dived to 3 to 6 elements through the thickness according to the Table. 1. With this meshing, the results relatively converge and, after that increase, the amount of mesh has not doesn't have a considerable effect on results.

It should be noted that the shrink of the elements starts from the middle of each layer in the direction of width and continues to both sides to the edge of each element, so that the elements close to the edges of the layer are smaller and denser than the elements in the middle of each layer as illustrated in Fig. 12. Observations show that the number of elements in length will not have a significant effect on the results.

This meshing was done in such a way that as we approach the free edge, the number of elements increases and their dimensions become smaller so that the effects of the free edge are examined more carefully. The multilayer material properties are assigned to the model layers in a partitioned manner in the software using a composite layer toolbox.

Due to the fact that the analysis is interlayer, layers cannot be used as shell elements and as a result, the type of layers with solid elements is selected [8].

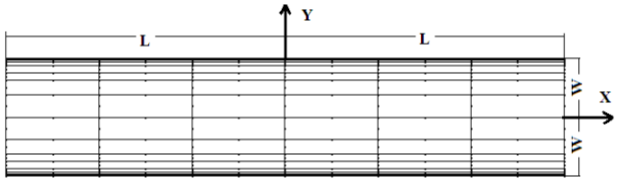

Fig. 11. Meshes in the x-y plane.

Table. 1. Mesh generation for model.

Mesh location	Order of mesh
Mesh in Length Direction	6 uniform elements
Mesh in Width Direction	14 non uniform elements
Mesh in Thickness Direction	Layer 1 & 8: 5 divisions (0.1, 0.2, 0.4, 0.2, 0.1) ×tL Layer 2 & 3 & 6 & 7: 6 divisions (0.1, 0.2, 0.4, 0.2, 0.1) ×tL Layer 4: 3 divisions (0.1, 0.2, 0.7) ×tL Layer 5: 3 divisions (0.7, 0.2, 0.1) ×tL

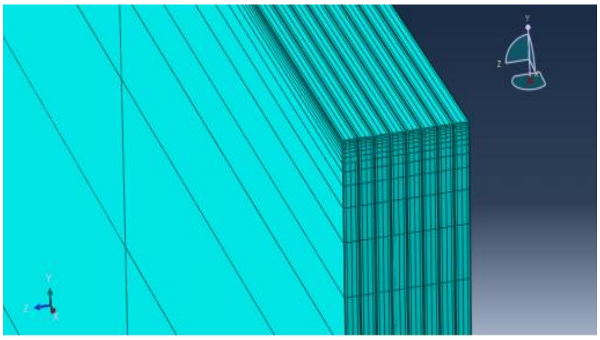

Fig. 12. Schematic of mesh through the thickness and near the free edge.

Table. 2. Mechanical properties of carbon-epoxy T300/5208 [9].

Elastic Stiffness (MPa)		Strength (MPa)	
E_{11}	137.11e3	Xt	1550
E_{22}	9.58e3	Xc	1090
E_{33}	9.58e3	Yt	59
ν_{12}	0.28	Yc	59
ν_{13}	0.28	Zt	59
ν_{23}	0.28	Zc	59
G_{12}	4.48e3	S_4	35
G_{13}	4.48e3	S_5	50
G_{23}	4.20e3	S_6	85

It is assumed that all layers have the same thickness and orthotropic behavior.

The values of modulus of elasticity, shear modulus and Poisson's ratio of the layers, which are carbon-epoxy T300/5208, are also given in Table. 2. [9].
Fig. 13. also shows one example of angles of the layers in the software.

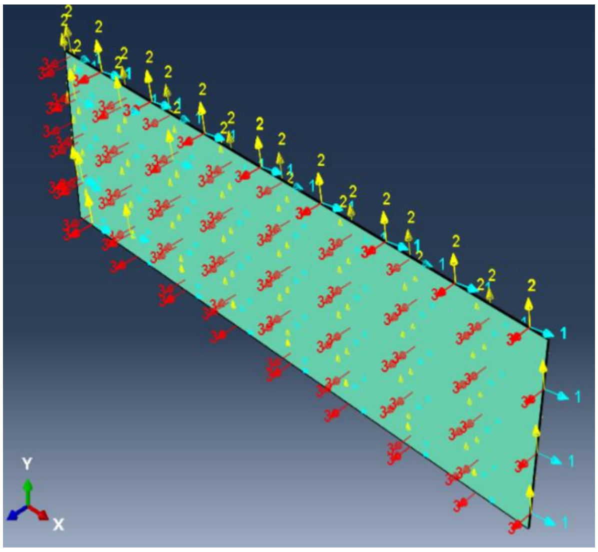

Fig. 13. An illustration of directions in layers.

Boundary conditions has important effect on results in a way that with fixing or opening one node results can change noticeably. Axial strain loading is applied to the multilayer along the x-axis. Also, to prevent the rigid body motion and rigid body rotation of the object during loading, it is necessary to apply appropriate boundary conditions. Improper loading or creating inappropriate boundary conditions will create additional constraints and consequently create unwanted stresses in the model. For cross-ply as well as quasi-isotropic conditions, the load is applied to the yz plane as uniaxial tension and load control in the x direction normally and bilaterally, but in the angle-ply layer due to the interaction effects of tension and shear, the load must be applied as displacement control.
Also, in the case of constraints on the model, it should be noted that the volume center of the model, in addition to the direction of the applied load (in the x direction), is also constrained in the y and z directions so that model does not move in any direction at the center. In other words, because the mid plane does not move in thickness it is fixed along z direction and middle of width in each element of laminate does not move a long y direction, so it is fixed in this direction.
When the angle plies are layed-up, in tensile test there is a rotation in plies but the center of each element is fixed and doesn’t move a long x direction so they are fixed in this direction. Actually, due to the absence of mutual influence of tensile and shear in the cross-ply, it is only sufficient to prevent rigid movement or rotation of the model by applying appropriate boundary conditions. The x-axis displacement constraint is applied to all nodes in the yz plane at the beginning and end of the entire multilayer.

Due to the simultaneous symmetry of shape and load, the displacement of the yz plane, which is exactly in the middle of the multilayer, is zero along the x-axis. Due to the existing symmetry, it is possible to create a constraint to move along the y-axis of the xz plane located exactly in the middle of the multilayer. By applying this constraint, the rigid transfer in the y direction as well as the rigid rotation around the z axis is prevented. With a similar argument, a constraint is applied to the xy plane that is exactly in the middle of the multilayer. By applying this constraint, the rigid transfer along the z-axis and the rigid rotation around the x-axis are prevented.
Due to the fact that there are interactions between tension and shear in the angle-ply layer, care must be taken in applying the load. Due to the possibility of rotating the layers locally or in general, creating a coupling constraint along the x-axis for the entire external yz plane, prevents the movement of these layers and thus creates unwanted additional stresses in the structure. To solve this problem, a very thin band is loaded for the nodes in the yz plane at the beginning and end of the whole layer. For two type of cross-ply layers, the tensional pressure is 660MPa and for two type of quasi-isotropic layers, the tensional force is 510MPa, as it shown in Fig. 14..

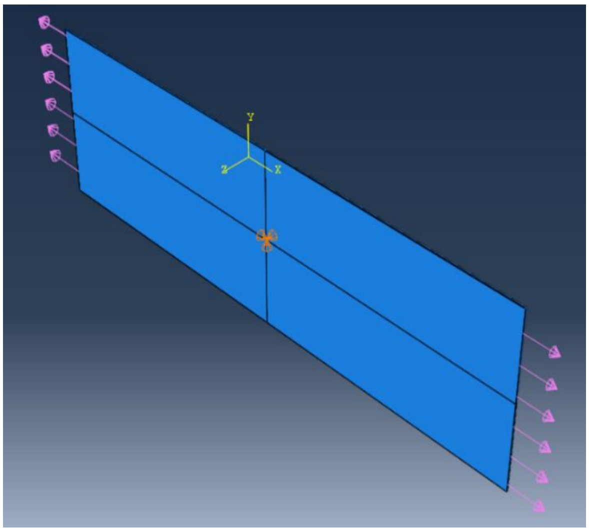

Fig. 14. Boundary conditions and constrains

At following, we are going to survey the stress distribution along two paths for two different angle-ply and two different quasi-isotropic layers. First path is along thickness and very close to free edge and second is along the width in the midplane of layers. For each layer, the interlayer stress diagram in thickness is first shown.
By defining a path along the thickness of the section (in the area with the highest Von Mises stress and away from the Saint Venant area) and then a path in the width with similar characteristics, the values of the stresses between the layers (interlaminar stresses) τ_{zz} (S33), τyz (S23) and τ_{xz} (S13) and within the layer (both interlaminar and in-plane stresses) σ_{xx} (S11), σ_{yy}

(S22) and (S12) τxy are shown in these paths. At following, the distribution of interlaminar stress (MPa) along the thickness(mm)of laminate for [10/-10]2s and [10(2)/-10(2)]s lay-ups are shown in figures (15) and (16).

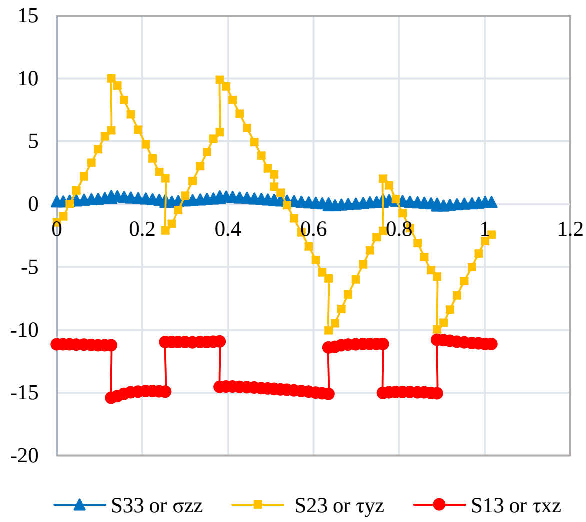

Fig. 15. The distribution of interlaminar stress (MPa) along the thickness (mm) for [10/-10]2s lay-up.

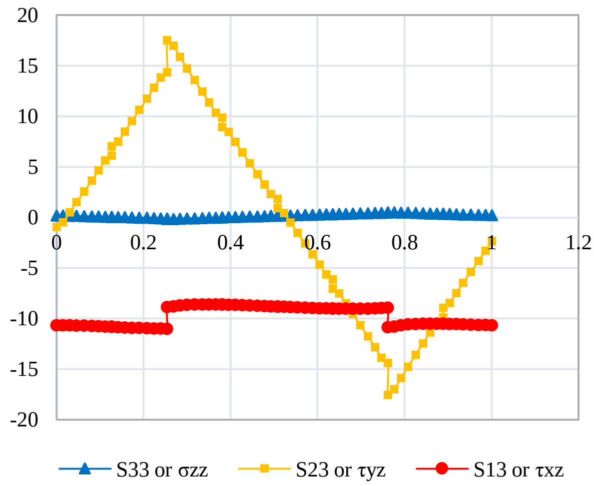

Fig. 16. The distribution of interlaminar stress (MPa) along the thickness(mm) for [10(2)/-10(2)]s lay-up.

In angle ply stacking sequence there is no mismatch between the layers but the mutual influence exists, because the fibers angle, so it's expected the amount of σ_{zz} can be negligible in front of τxz. In multilayers, angle-ply mismatch in the coefficient ηxy,x results in an interlayer shear force of F_{zx}.

The maximum value of F_{zx} occurs at the boundary of the layers θ and -θ, and when the thickness of the layers is halved, this maximum value is also halved. In general, angle-ply has much lower σ_{zz} values.

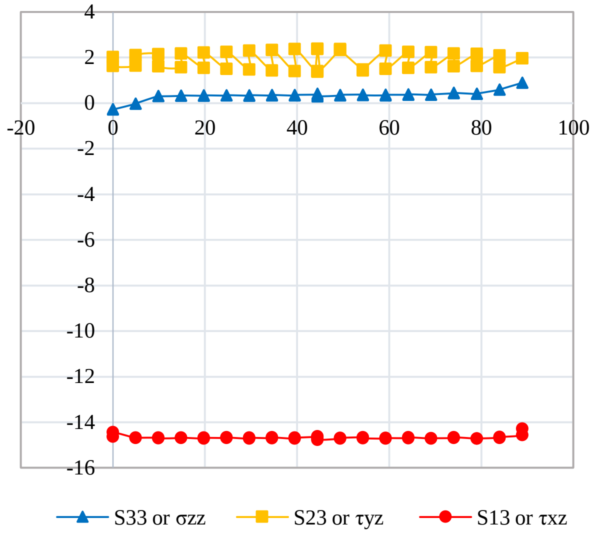

Fig. 17. The distribution of interlaminar stress (MPa) of midplane along the width (mm) for [10/-10]2s lay-up.

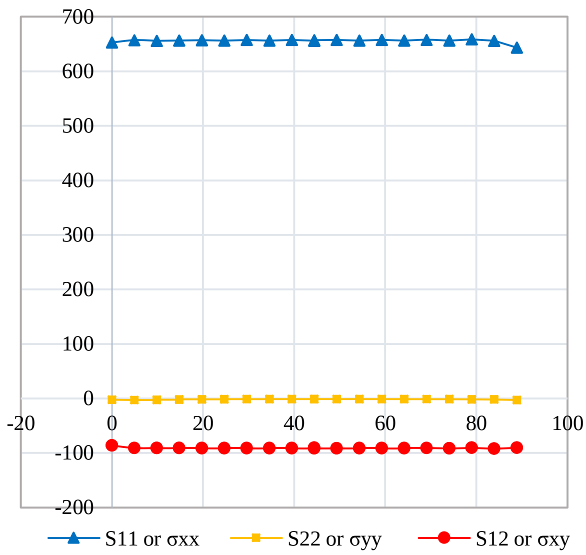

Fig. 18. The distribution of inplane stress (MPa) of midplane along the width (mm) for [10/-10]2s lay-up.

The distribution of free edge forces F_{yz}, M_z and F_{zx} in the direction of thickness for the layer is obtained by cumulative integral method. The damage mode in the layers is angle ply matrix cracking.

This mode of damage requires much more energy to start the destruction than the mode of separation, but the growth of the mode occurs very quickly.

At following, interlaminar and inplane stresses of midplane along width for two different kind of previous angle-ply layers are shown in Fig. 17., Fig. 18., Fig. 19. and Fig. 20..

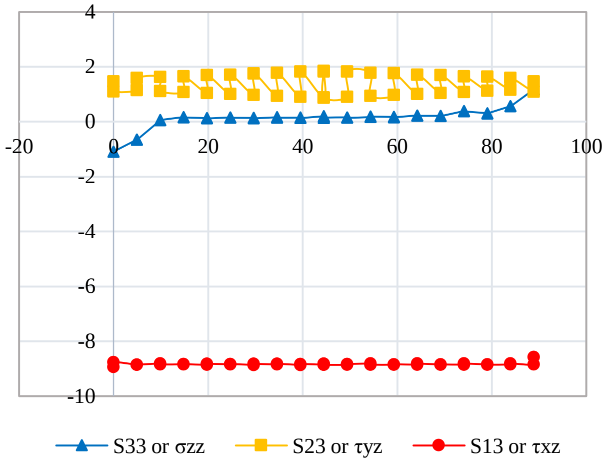

Fig. 19. The distribution of interlaminar stress (MPa) of midplane along the width (mm) for [10(2)/-10(2)]s lay-up.

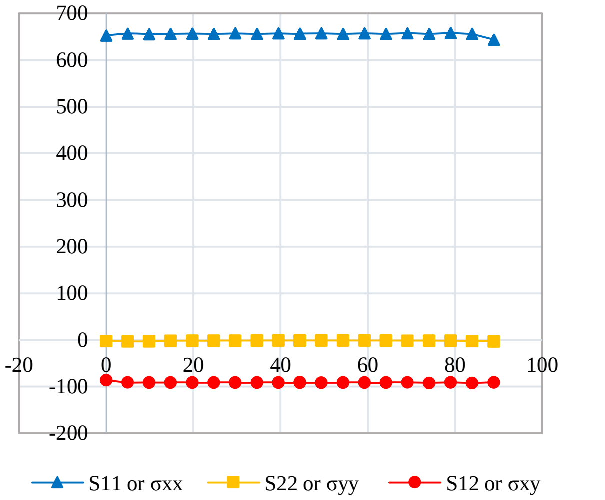

Fig. 20. The distribution of inplane stress (MPa) of midplane along the width (mm) for [10(2)/-10(2)]s lay-up.

As expected, the interlaminar and inplane stresses of midplane along the width of model for both layups are constant. The amount of σ_{zz} is zero in interlaminar analysis and the amount of σ_{yy} is zero in inplane analysis too. The amount of σ_{xx} for both layups equal 660MPa, as we applied such an equal pressure. At following, we are going to focus on two type of quasi-isotropic layups which are [0/45/-45/90]s and [90/-45/0/45]s. It should be mentioned the previous defined paths are still used here. The distribution of interlaminar stress (MPa) along the thickness(mm) of laminate for [0/45/-45/90]s and [90/-45/0-45]s lay-ups are shown in Fig. 21. and Fig. 22.

Unlike cross-ply and angle-ply layers, in a quasi-isotropic multilayer, all three interlayer quantities F_{yz}, F_{zx}, and Mz have non-zero values. Similar to before and as expected, the shear forces change linearly along the layers.

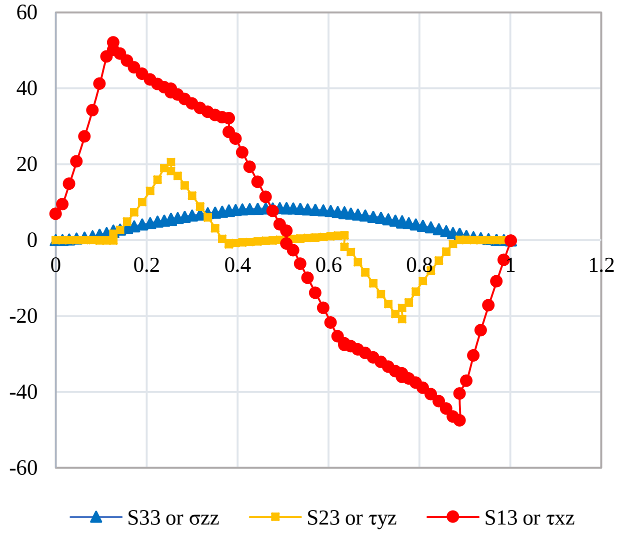

Fig. 21. The distribution of interlaminar stress (MPa) along the thickness (mm) for [0/45/-45/90]s lay-up.

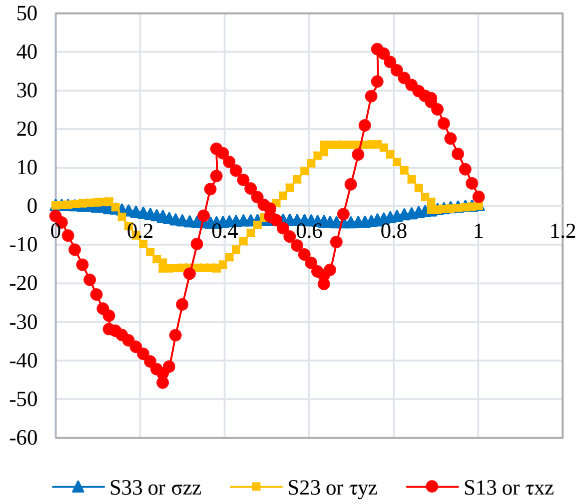

Fig. 22. The distribution of interlaminar stress (MPa) along the thickness (mm) for [90/-45/0/45]s lay-up.

The maximum amount of shear force always occurs at the boundary of the two layers, but the maximum amount of moment between the layers is not and does not always occur in the middle. In the direction of the layers, the changes in shear forces are linear.

As can be seen, extreme shear stresses occur at the boundary of the layers. It can be seen that σ_{zz} stress is negligible in both. Particularly for quasi-isotropic layups, interlaminar forces and moments which can obtain from the integration of the Fig. 21. and Fig. 22. At following, interlaminar and inplane stresses of midplane along width for [0/45/-45/90]s and [90/-45/0-45]s quasi-isotropic layers are shown in Fig. 23., Fig. 24., Fig. 25. and Fig. 26..

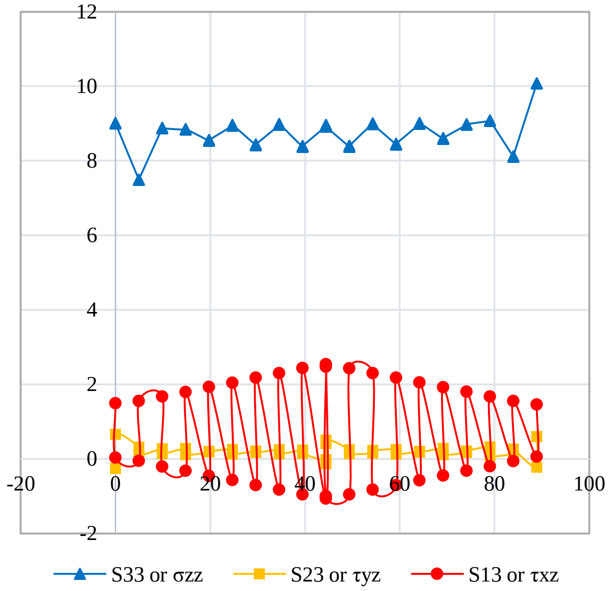

Fig. 23. The distribution of interlaminar stress (MPa) of midplane along the width (mm) for [0/45/-45/90]s lay-up.

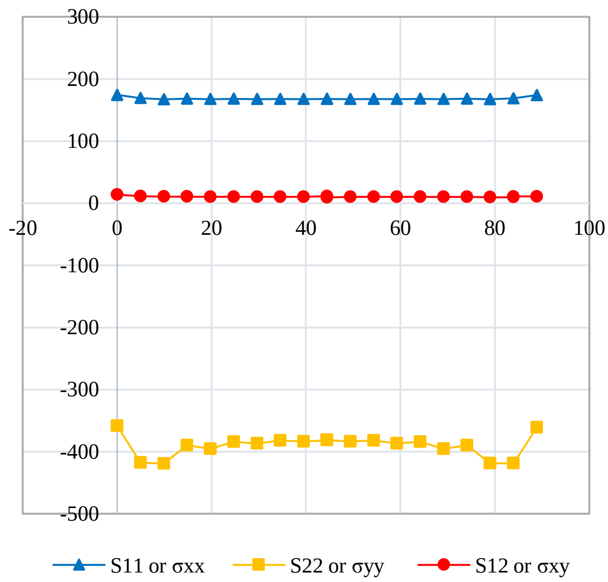

Fig. 24. The distribution of inplane stress (MPa) of midplane along the width(mm) for [0/45/-45/90]s lay-up.

As expected, the interlaminar and inplane stresses of midplane along the width of model for both layups are nearly constant. The amount of shear stresses in interlaminar analysis like τ_{yz} and τ_{xz} are approximately zero. In terms of inplane analysis the amount of τ_{xy} for the first layup equals zero but it has a non-zero value for the second one.

The difference is because of the stacking sequence. By comparing the stress distribution across the width of the plate, it can be said that the quasi-isotropic layer is better resistant to the interlayer separation damage mode.

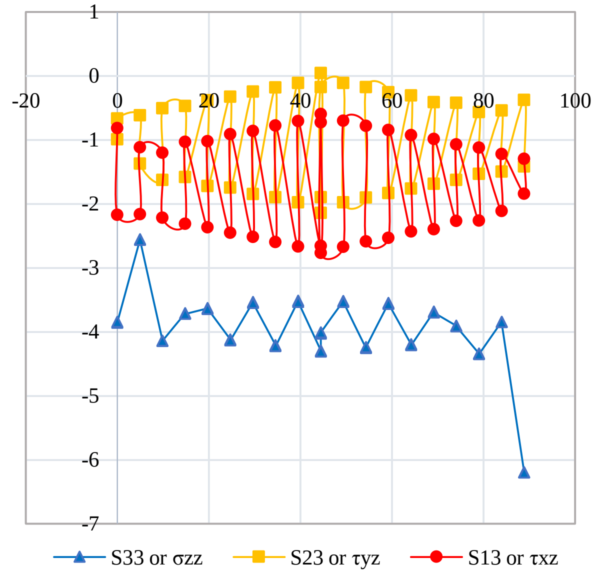

Fig. 25. The distribution of interlaminar stress (MPa) of midplane along the width (mm) for [90/-45/0/45]s lay-up.

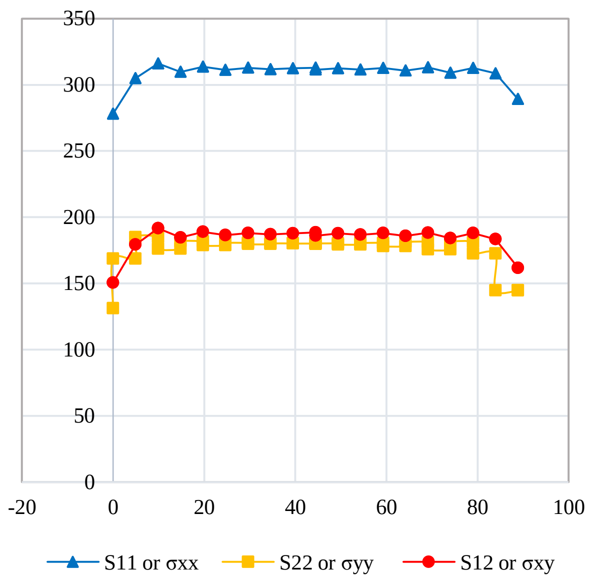

Fig. 26. The distribution of inplane stress (MPa) of midplane along the width (mm) for [90/-45/0/45]s lay-up.

4. Results and Discussion

Basically, any kind of discontinuity, both geometric and material, makes analytical solutions difficult and sometimes impossible. Although geometric discontinuities in homogeneous and inhomogeneous materials are created as needed, material discontinuities in inhomogeneous materials and composites are inevitably inherent. Therefore, the effect of material discontinuity should always be considered in the analysis of composite materials, and analyzes that do not consider material discontinuities, especially near free edges and around geometric discontinuities, are inaccurate and have no necessary efficiency. The mechanical coupling created in the composite material intensifies the effect of material discontinuity between the layers and especially at the free edge, and as a result leads to the separation (delamination) of the layers and its failure. When a cross-ply or angle-ply thin laminate is symmetrical or asymmetrical, of limited width and unlimited length, or of limited width and limited length under any type of mechanical, thermal, moisture and electrical loads; due to the material discontinuity between its layers and also the changes of in-plane layer stresses near the boundaries, interlaminar stresses have arisen in it and when these stresses reach the free edges, these stresses create an effect called the free edge. In this case, there are two distinct and debatable areas on the multilayer. These areas are the inner area and the outer area (boundary layer). In the interior, the classical lamination theory (CLT) can be used with a good approximation. But in the boundary area, the three-dimensional stress field prevails and the theories of three-dimensional elasticity should be used. Since it is not possible to solve three-dimensional equations of elasticity for such problems, analytical, analytical-approximate or numerical methods should be used to solve such problems. The main purpose of studying the effect of free edges is to determine the range in which the plane stress assumptions are valid and also to determine the range in which these assumptions are not valid.

5. Conclusion

In this study, an eight-layer carbon-epoxy composite was subjected to uniaxial tension and the interlayer stresses in terms of thickness and width near the free edges were studied. After applying pressure and restraint and performing the analysis, the following results can be mentioned:

1. Reducing the harmful effects of the environment is one of the concerns of engineers in the field of equipment design today. One of the effective factors in reducing the fuel consumption of aircraft is reducing the weight of these structures. The use of composite wings instead of metallic wings reduces fuel consumption, which in turn reduces the harmful effects on the environment.
2. The results obtained from the stress distribution across the multilayer show that σzz is distributed symmetrically across the width of structure.
3. The results show that τyz is distributed asymmetrically across the width of multilayer.
4. As expected, stresses like σzz is insignificant in angle-ply layers, and it is obvious that layers that are a combination of this type have all the stress components.
5. In the angle-ply layer, τxz stresses were observed mainly at the point of substitution of the layer angle from θ to $-\theta$ degrees.
6. In angle-ply and quasi-isotropic layers, σzz stresses are very small in thickness.
7. It can be said that the quasi-isotropic layer has better resistance against the damage mode of interlayer separation.
8. The average of normal and shear stresses in the layer thickness in quasi-isotropic layer is higher than angle-ply.

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