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Reduction of Stress Concentration at Delaminated Composite Laminate

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ABSTRACT

Now a days, most of structures as specially in Automotive & Aerospace structures are made with composite materials. So a clear idea is needed to study the behavior of that structures under different load condition. One of the method is to carry out is through Finite element analysis. In this article, we use different composite laminate structures to compute Interlaminar normal stresses at delaminated composite laminate. The laminates are modeled with 20 noded isoperimetric brick element (ANSYS element Solid 95) and are subjected to uniaxial strain. The problem is analyzed for quarter domain due to symmetry. This work demonstrates that wrap-around technique reduces inter laminar normal stress at the crack tip considerably. The interlaminar normal stress computed using finite element analysis of assumed initial delaminations at free edge are used for this study. The effect of wrap-around on reduction of laminar normal stress is discussed.

Keywords:*Delaminated Composite laminate, Interlaminar normal Stress, ANSYS.*

1. INTRODUCTION

Israelites using bricks made of clay and reinforced with straw are an early example of application of composites. The individual constituents, clay and straw, could not serve the function by themselves but did when put together. Some believe that the straw was used to keep the clay from cracking, but others suggest that it blunted the sharp cracks in the dry clay. Historical examples of composites are abundant in the literature. Significant examples include the use of reinforcing mud walls in houses with bamboo shoots, glued laminated wood by Egyptians (1500B.C.), and laminated metals in forging swords (A.D. 1800). In the 20th century, modern composites were used in the 1930s when glass fibers reinforced resins. Boats and aircraft were built out of these glass composites, commonly called *fiberglass*. Since the 1970s, application of composites has widely increased due to development of new fibers such as carbon, boron, and aramids, and new composite systems with matrices made of metals and ceramics. [1]

At the beginning of the twentieth century, dwindling deposits of important resources and their escalating prices triggered off an intensive search for synthetic, or manmade, substitute materials. The demand from the fast-growing industries was increasing in line with fundamental technical changes and could no longer be satisfied with natural materials alone. In time, countless compounds, including a high number of plastics, were synthesised from naturally occurring raw materials such as coal, coal tar, crude oil, and natural gas. 1) The object behind combining **different materials** to form a **composite** with enhanced properties and synergetic effects is par for the course in nature. A section through a paracortical cell in merino wool or through a bamboo stems exhibits structures similar to the micrograph of a unidirectional carbon-fibrereinforced epoxy resin (CF-EP). Not only in the microstructure can nature be seen as the progenitor of fibre-reinforced plastics, but also in the application of lightweight design principles

In particular the aerospace industries benefit from these low structural weights, which contribute considerably towards cutting energy requirements and enhancing performance. The reasons behind the use of high-performance fibre composites in space travel are primarily financial ones. In view of the high costs for energy, the space agencies are willing to spend up to 25,000 euros for every kilogram saved. For the aeronautics industry this is 250 to 750 euros per kg, in the automobile industry 0 to 2.50 euros per kg (except in racing). [2]

One of the problems with laminated composites is their low interlaminar toughness which makes them liable to delaminate at free edges or in regions of high stress gradient. Delamination or interlaminar fracture can be caused by high interlaminar stresses that arise due to mismatch in elastic properties between plies at free edges in composite laminates. Laminated composite structures manufactured using conventional lay-up technique is prone to edge delamination. The presence and growth of delamination in composite laminates may lead to severe reliability and safety problems, such as reduction of structural stiffness, strength and fatigue life, disintegration of the material etc. Therefore, understanding the behavior of stress concentration near the crack tip is of critical importance in

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the assessment of structural integrity of advanced composite materials and structures.

Interlaminar stress in composite structures usually results from the mismatch of engineering properties between plies. These stresses are the underlying cause of delamination initiation and propagation. Delamination is defined as the cracking of the matrix between plies.

Because of the adverse effect of delamination on the integrity of composite structures, numerous investigators have studied delamination phenomena in finite-width composite laminates subjected to uniaxial load. The response of a finite-width composite laminate under uniform axial strain is treated through the application of classical elasticity theory. Results for material properties typical of a high modulus graphite-epoxy composite material system were obtained by finite difference method [3].

W.E. Howard et al, [4] has used the Generalized plane strain finite-element analysis to predict singinificant reduction of interlaminar normal stresses when a U-shaped is bonded to the edge of a composite laminate. Suitable finite-element models are developed for addressing the pertinent behavioral factors such as highly variable transverse stresses near the free edge, that governs delamination is reduced, but the interlaminar normal shear stress is not significantly reduced, nor does it influence delamination.

G.S. Amrutharaj et al, [5] has investigate the The concept of a fracture process zone where damage takes place is used to analyse the delaminations at the free edges of angle ply laminates under uniaxial tension. The use of a fracture process zone removes the singularity in the interlaminar stresses and enables the initiation and growth of delaminations to be modelled for a perfect laminate without any assumed prior defects.

Mohammed Haneef et al, [6] has studied, the delamination effect on composite with two models by using ANSYS software package.

P. L. Choudhury et al,[7] has demonstrates that wrap-around technique reduces delamination considerably. The strain energy release rates computed using finite element analysis by the help of ANSYS of assumed initial delaminations were used for this study.

The delamination is found to be sensitive to fiber orientation, laminate stacking sequence, and ply thickness [8-12]. For a laminate consisting of identical plies, some stacking sequences are prone to delaminate, and others can suppress delamination.

For the prevention of edge delamination, several techniques have been proposed, such as free-edge cap reinforcement [13], free-edge stitching [14], hybridization [15], stacking method in balanced symmetrical laminates [16] and adhesive-layer reinforcement [17].

In view of above, it is clear that excellent studies have been made on free edge effects and their suppression for uncapped and capped composite laminates. However, problems encountered with already delaminated composite structures (containing delamination at free edge) were not addressed properly. An understanding therefore is required to be developed on the behavior of delaminated composite structures with and without cap and wrap-around since the existing delamination could be critical to the laminated composite structure's final failure. The present study is motivated by a requirement to develop an understanding on the above mentioned behavioral aspect. The present study aims at the studies of the effect of Wraparound on reduction of stress concentration at crack tip which leads to the crack propagation. ANSYS 14 [18] has been used to develop models for laminates, (+45/-45)s and (+22/-22/90n)s_n= 1,2,4,6 and perform FE analyses. Although no formulation has been attempted for this study, an understanding on behavioral aspect of the delaminated composite structures is developed here.

2. MODEL VALIDATION:

Before taking up delamination analyses on delaminated composite laminates, FE analyses were undertaken on following undelaminated composite laminate. FE models were developed for the laminates having the following layup specification and material [13]. Due Symmetry conditions one fourth model is define in ANSYS with uniform displacement boundary conditions, to the extent of zero on one end plane and a finite displacement of ε_z on the other have been applied.

Lay-up Specification (45/-45)s

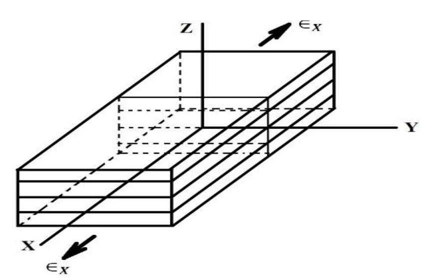
Orthotropic Material Model:

E_1 = 137.89 Gpa; $E_2 = E_3$ = 14.48 Gpa; $G_{12} = G_{13} = G_{23}$=5.86 Gpa,

$\mu_{12} = \mu_{13} = \mu_{23} = 0.21$

Laminate Specification: The dimensions of the laminate quadrant were taken to be b=25.4 m by h=2.54 cm; hence the width to thickness ratio of the laminate is 10.

The laminate was subjected to an initial strain of .001 cm/cm in all analyses.



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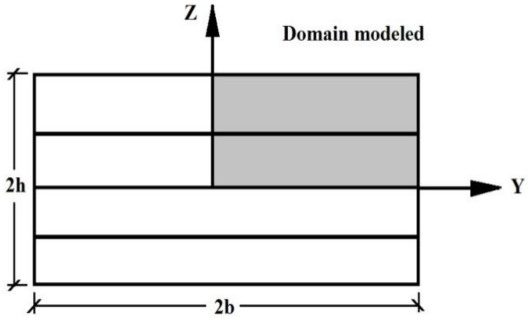

Figure 1: Laminate geometry and loading

A finite element calculation was made to obtain the distribution of interlaminar normal stress (**ILNS**), σ_z along the interface and across the width. The finite element calculation resulting from the strain load are compared with the distribution obtain by P.R. heyliger and J.N. Reddy [6].

Figure 2 shows the mesh distribution system in (+45/-45) s. Fine meshes are carried at free edge because maximum stress variation occurs at free edge.

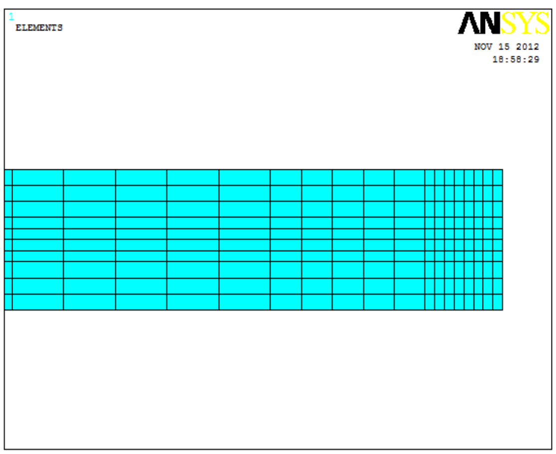

Figure 2: Mesh distribution system

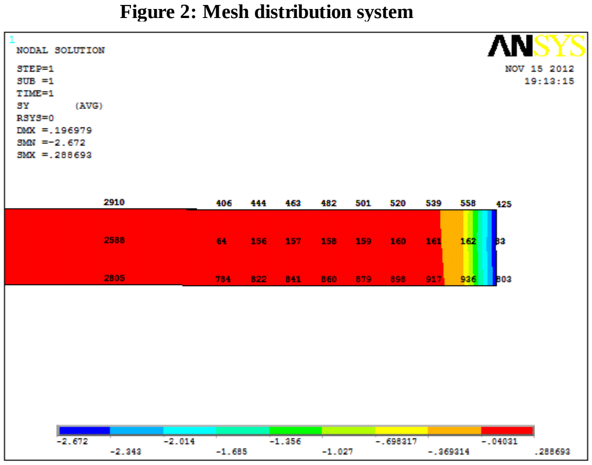

Figure 3: Variation of ILNS at +45/-45 interface

Figure 3: shows the variation of inter laminar normal stress (ILNS). From that contour it is clear that maximum stress variation occur at free edge.

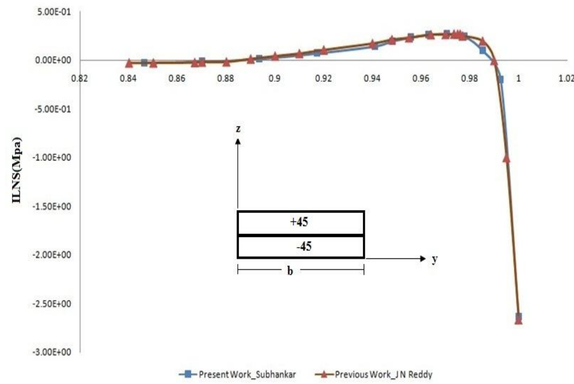

Figure 4: Comparison of ILNS (σz) distribution across width(y/b) at laminate interface

Figure 4 shows the graphical representation of ILNS at the free edge. The plot represent the comparison of ILNS of present work with the result obtain by J.N. Reddy [6]. The plot shows that there is a close agreement between the two distributions which provides a degree of confidence that the model is in working order

3. PROBLEM DEFINITION & SCOPE OF PRESENT INVESTIGATION:

Defination: The objective is to study the stress concentration around the crack tip in delaminated composite, and wrap-around delaminated models.

Scope of the present work:

Modeling of delaminated composite with initial crack at free edge with-

- Lay-up specification: (22/-22/90n)s_n=1,2,4,6,
- Crack is assumed to be present in -22/90 interfaces.
- Orthotropic Material Model: E_{11}=142.20E+09 Pa; E_{22}=E_{33}= 7.27E+09 Pa; G_{12}=3.43E+09 Pa, G_{23} = 2.85E+09 Pa; μ_{12}= 0.246
- Laminate Specifications: Ply Thickness, h= 0.00014 m; Width, B=140 h; axial strain, εx= 1%; length of delamination, a=6h.

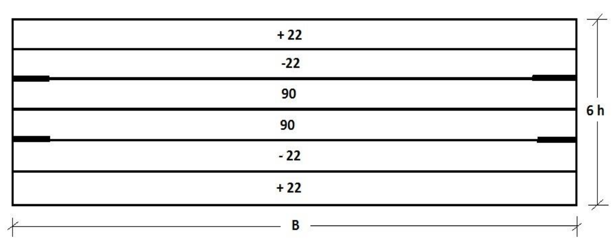

Figure 5: Delaminated model without wrap-around (+22/-22/90)s

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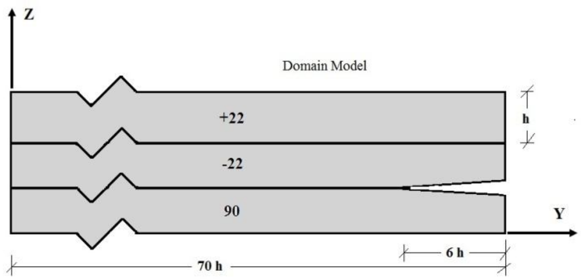

Figure 6: One fourth model without wrap-around

Delaminated models (with and without wrap-around) the above family of composite laminates has been chosen for studies because these are delamination specimens. Consider initial finite delamination, FE Models were developed for the laminates (Figure 5 & 7) having the above specification and material specification [7].

The decency of the models with wrap-around is that no extra material layer is provided for wrap-around. Outer two plies of +22 deg. and -22 deg. Fibre orientation run around the inner 90 deg, plies. U-shaped delaminations are seen at the interface between -22 deg. And 90 deg layers of the delaminated models with wrap-around, figure 7.

Figure 6 & 8 shows the one fourth model of Delaminate laminate of with and without wrap-around (+22/-22/90)s

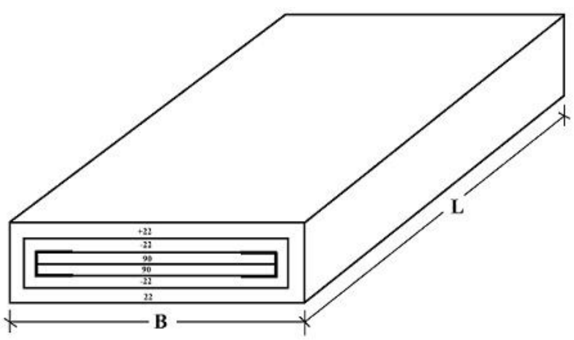

Figure 7: Delaminated model with wrap-around (+22/-22/90)

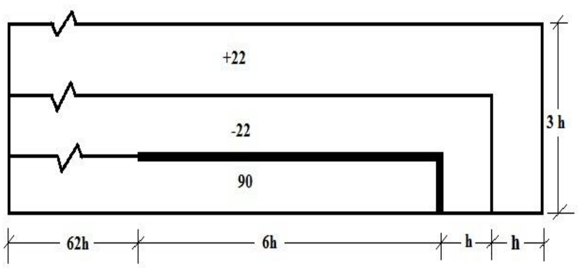

Figure 8: One fourth model with wrap around

Methodology

Computational method is carried for finding out interlaminar normal stresses around the crack tip.Commercial finite element analysis software ANSYS 14.0 has been used for that purpose.

Assumption:

- The material in the lamina comprising the laminate is homogeneous and orthotropic even though the lamina material is usually a fiber reinforced system.
- +22 and -22 fibres woven layer separate out as two different layers
- General plane strain

4. FINITE ELEMENT ANALYSIS:

For performing the finite element analysis on the Delaminated models without wrap-around (+22/-22/90n)s, n=1,2,4,6 and wrap-around (+22/-22/90n)s, n=1,2,4,6 are modeled using Mechanical APDL (ANSYS) 14.0. Meshes were created using ANSYS software. Finite element meshing of the all eight models was done with three dimensional 20 noded isoparametric brick element (ANSYS element solid 95). Science the maximum stress is generated at crack tip, fine meshes were done around the crack tip. However, science the use of many elements in the model may severely reduced the computational efficiency; the no of elements was selected to achieve both the geometric and computational efficiency. The total no of elements used for the models are given bellow:

Models	No of elements
Delaminated Model without wrap-around Case 1 (+22/-22/90n)s, n=1	10248
Delaminated Model without wrap-around Case 2 (+22/-22/90n)s, n=2	13664
Delaminated Model without wrap-around Case 3 (+22/-22/90n)s, n=3	20496
Delaminated Model without wrap-around Case 4 (+22/-22/90n)s, n=4	27328
Delaminated Model with wrap-around case 1 (+22/-22/90n)s, n=1	10017
Delaminated Model with wrap-around case 2 (+22/-22/90n)s, n=2	16500
Delaminated Model with wrap-around case 3 (+22/-22/90n)s, n=3	15456
Delaminated Model with wrap-around case 4 (+22/-22/90n)s, n=4	22680

Next finite element models are assigned to material properties. Symmetry condition have been exploited in the thickness and breath direction only that means only quarter

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model are assigned for the analysis. The computer runs are made by imposing uniform displacement boundary condition, to the extent zero on one end plane and a finite displacement of about 1% on the other. The laminates considered are both (a) symmetric about the mid plane and (b) balanced i.e., for each laminaoriented at an angle + theta degree to the axix, there is a lamina oriented at – theta degree.

The different mesh distribution system for all eight models are shown bellow.

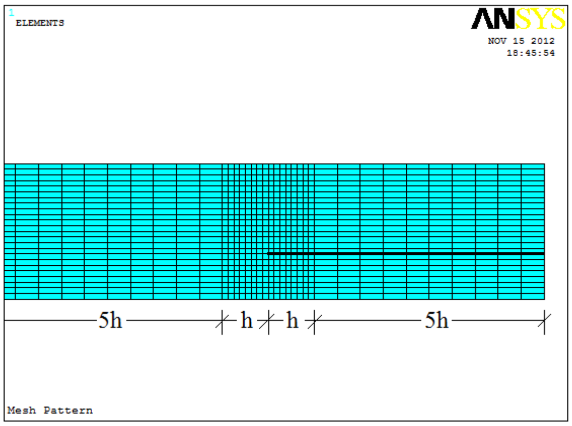

Figure 9: Mesh distribution without wrap-around Case 1

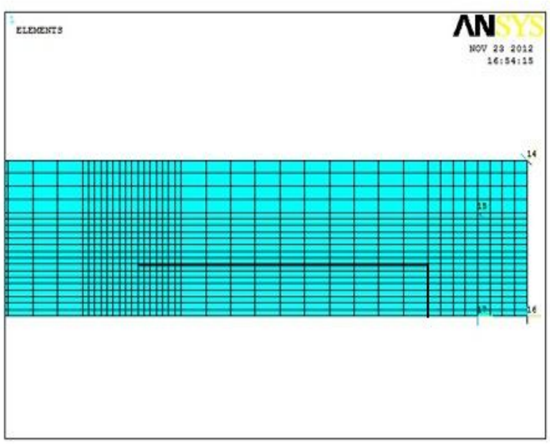

Figure 10: Mesh distribution with wrap-around case 1

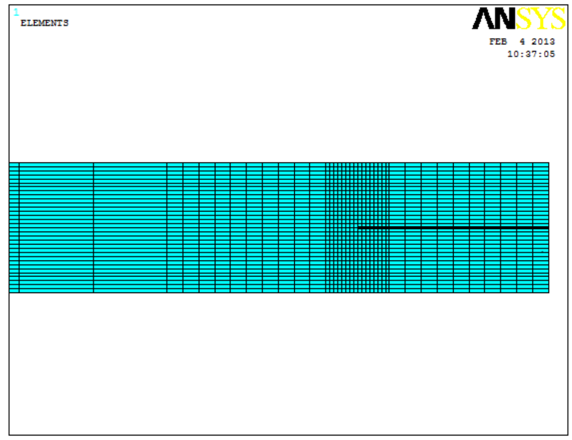

Figure 11: Mesh distribution without wrap-around Case 2

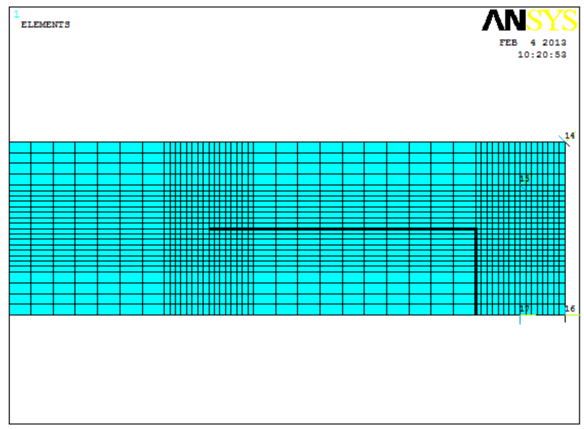

Figure 12: Mesh distribution with wrap-around case 2

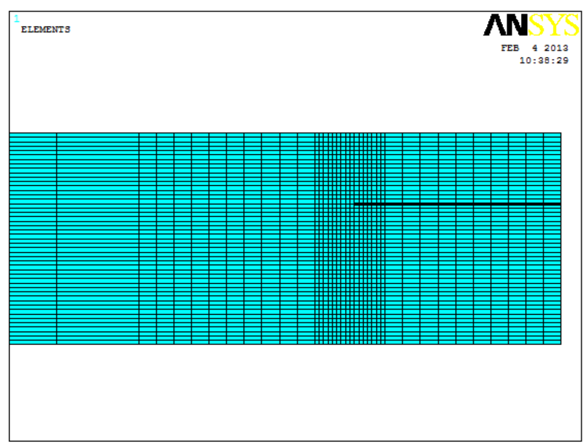

Figure 13: Mesh distribution without wrap-around Case 3

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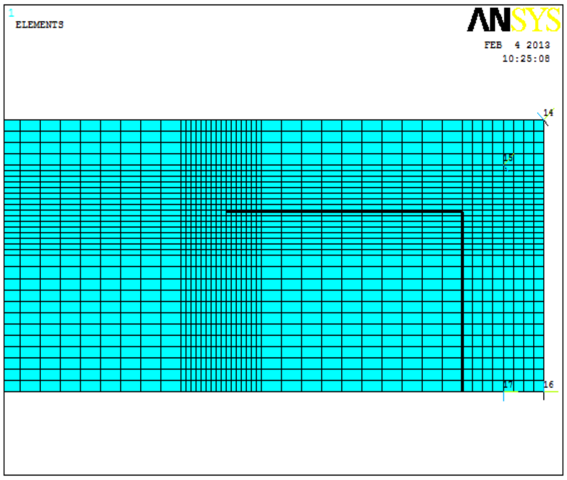

Figure 14: Mesh distribution with wrap-around case 3

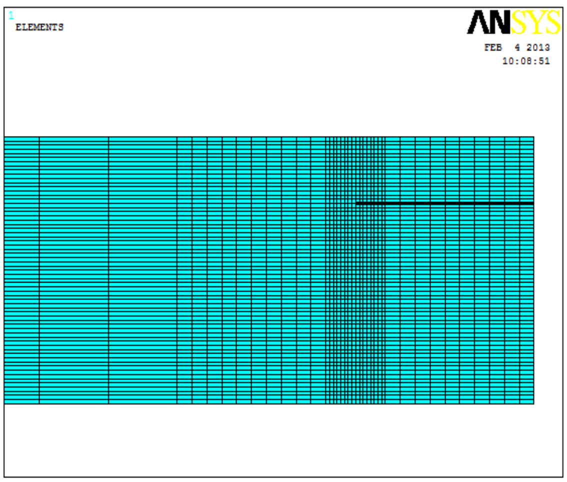

Figure 15: Mesh distribution without wrap-around Case 4

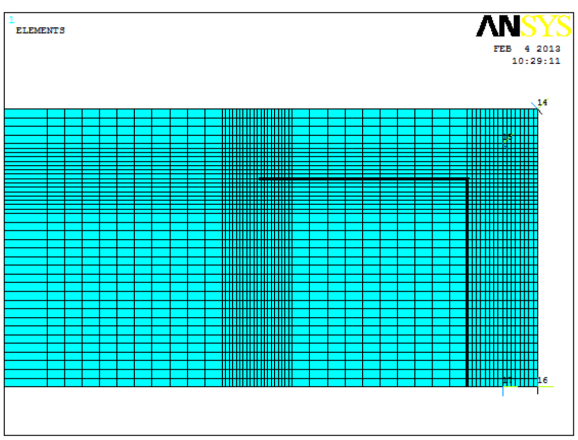

Figure 16: Mesh distribution with wrap-around case 4

5. RESULTS AND DISCUSSION

Delaminated model with and without wrap-around subjected to uniaxial strain is considered to study the effect of interlaminar normal stress around the crack tip. 1% axial strain is applied to the models. The results are as follows

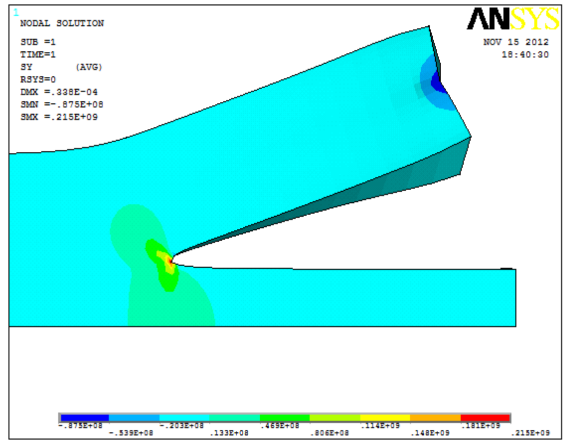

Figure 17: Contour of normal stress Delaminated model without wrap around case 1

Figure 17 shows contour of normal distribution in Delaminated model without wrap around case 1. Color Pattern shows variation of stress around the crack tip. Maximum stress of 1.97E+08 Pa can be observed at the crack tip which leads to the propagation of fracture. Figure 18 shows the enlarge view of Delaminated model without wrap-around Case 1 which represents the variation of normal stress around the crack tip by help of color contour where red represent the maximum stress location and cyan represent the minimum stress location.

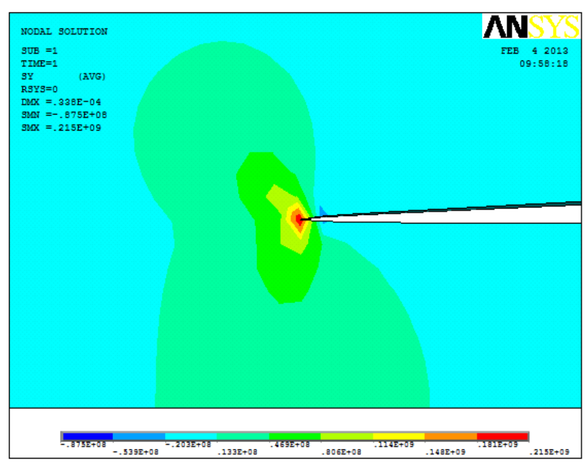

Figure 18: Variation of normal stress around the crack tip delaminated model without wrap-around Case 1

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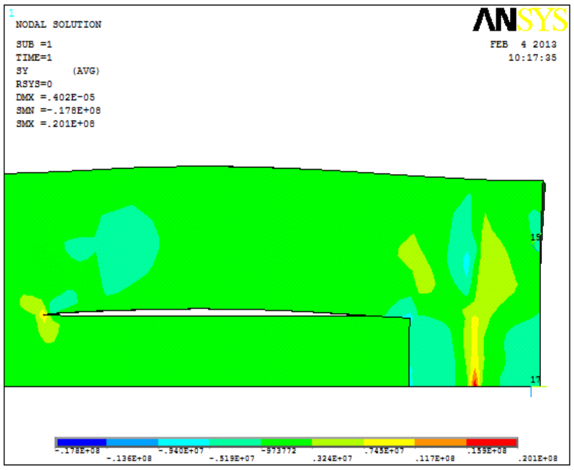

Figure 19: Contour of normal stress Delaminated model with wrap around Case 1

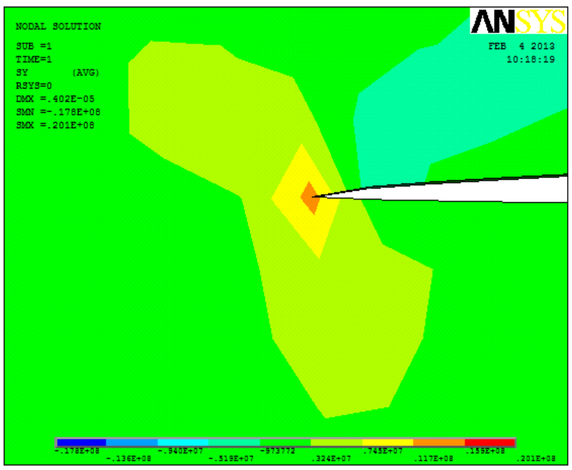

Figure 20: Variation of normal stress around the crack tip delaminated model with wrap-around Case 1

Figure 19 shows the contour of normal stress distribution of delaminated model with wrap-around case 1 where Figure 20 represent the enlarge view of that which shows the variation of stress around the crack tip.

By using Wrap-around technique the interlaminar normal stress is reduce drastically. The magnitude of stress at the crack tip for Wrap-around model is 0.13309 as compared to 1.97E+08 Pa for without wrap-around (+22/-22/90) laminate. The comparison of interlaminar normal stress along the width upto the crack tip for these 2 models is shown below.

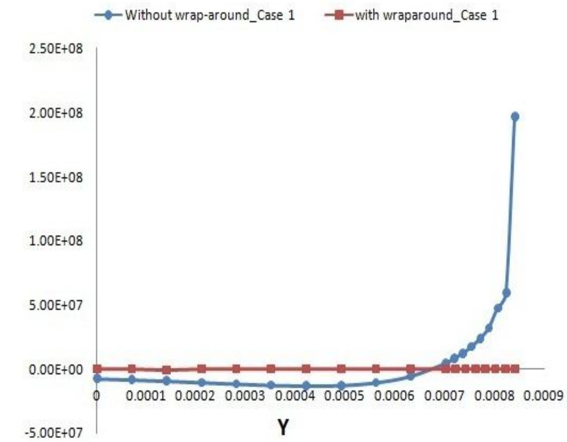

Figure 21: Distribution of the interlaminar normal Stresses along width case 1

Fig. 21 shows the effectiveness of capped and wrap-around model on reduction of interlaminar normal stresses around crack tip.

The corresponding contour and variation of stress around crack tip for other three cases are given bellow:

Case 2: (+22/-22/90n)s, n=2

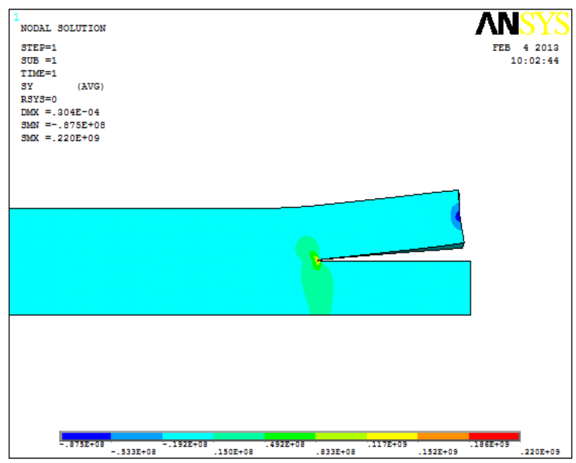

Figure 22: Contour of normal stress Delaminated model without wrap around case 2

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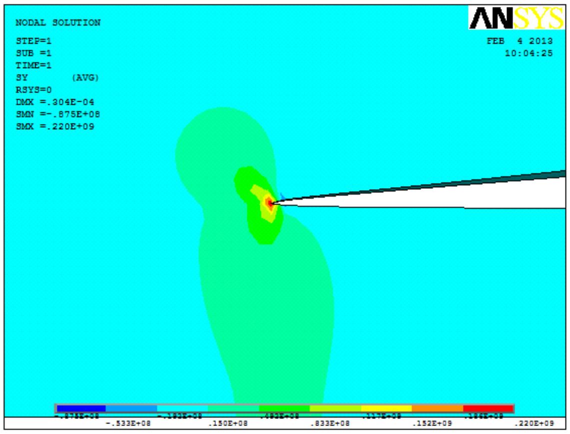

Figure 23: Variation of normal stress around the crack tip delaminated model without wrap-around Case 2

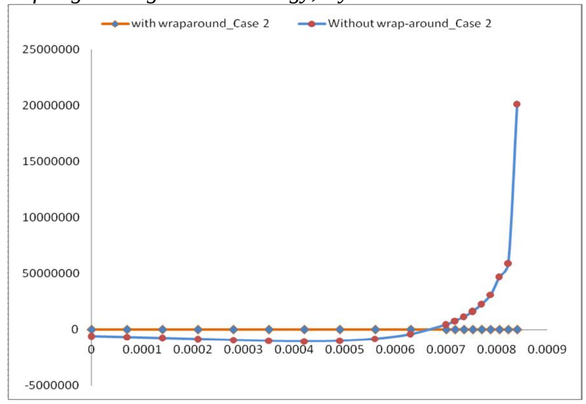

Figure 26: Distribution of the interlaminar normal Stresses along width case 2

Case 3: (+22/-22/90n)s, n=3

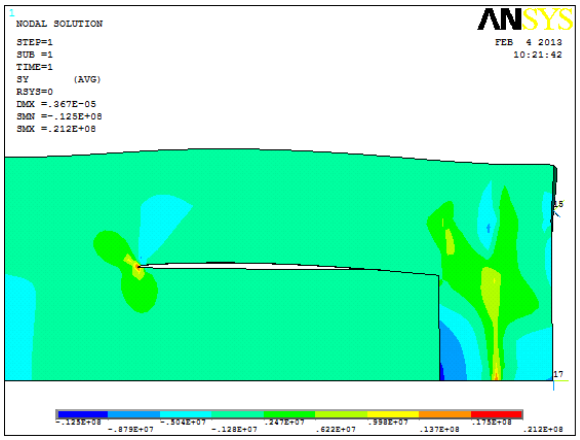

Figure 24: Contour of normal stress Delaminated model with wrap around Case 2

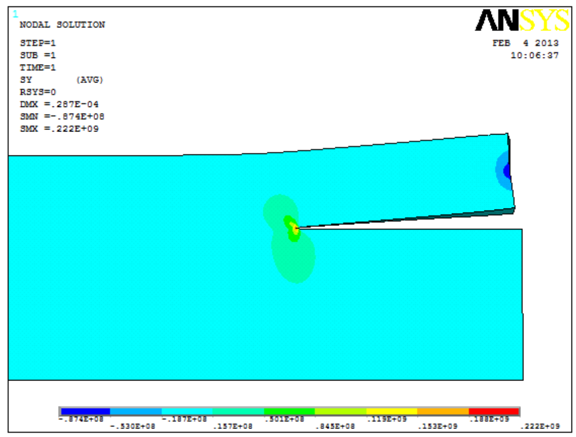

Figure 27: Contour of normal stress Delaminated model without wrap around case 3

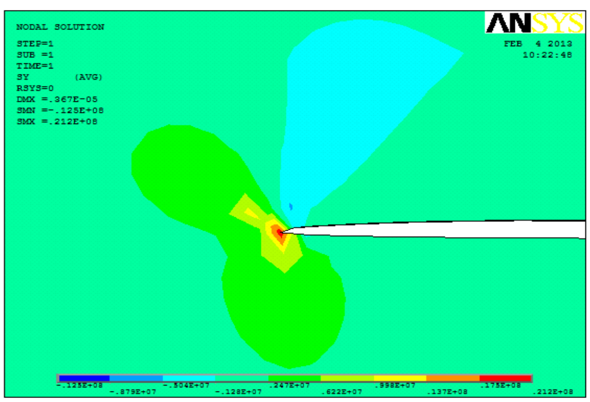

Figure 25: Variation of normal stress around the crack tip delaminated model with wrap-around Case 2

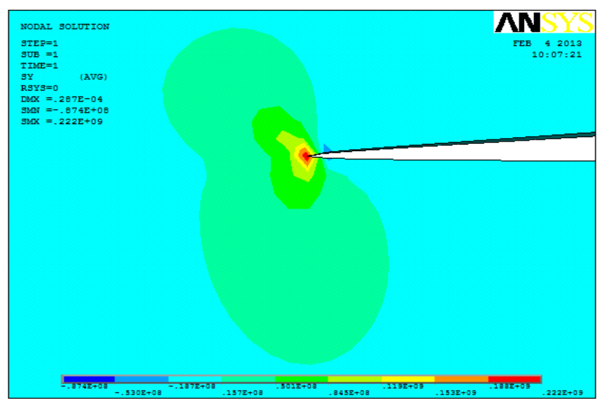

Figure 28: Variation of normal stress around the crack tip delaminated model without wrap-around Case 3

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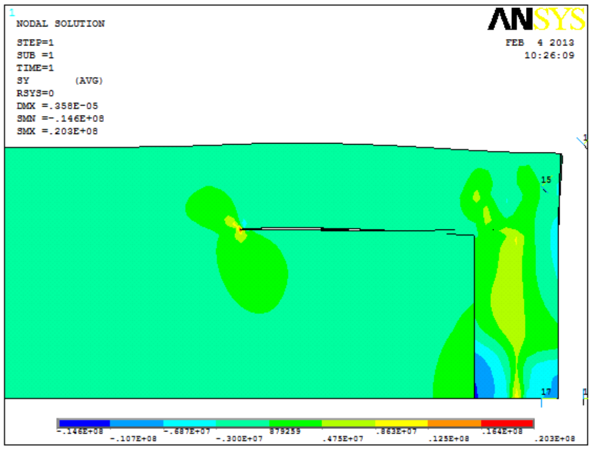

Figure 29: Contour of normal stress Delaminated model with wrap around Case 3

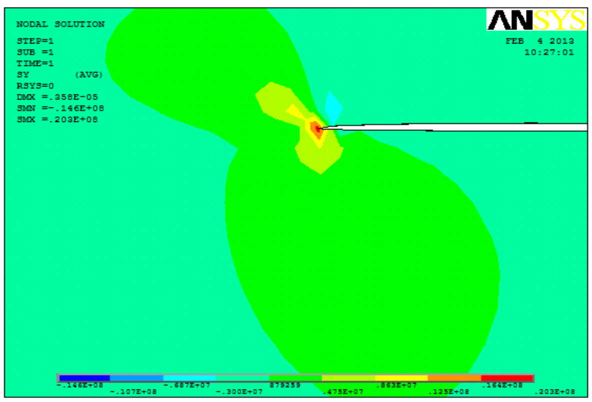

Figure 30: Variation of normal stress around the crack tip delaminated model with wrap-around Case 3

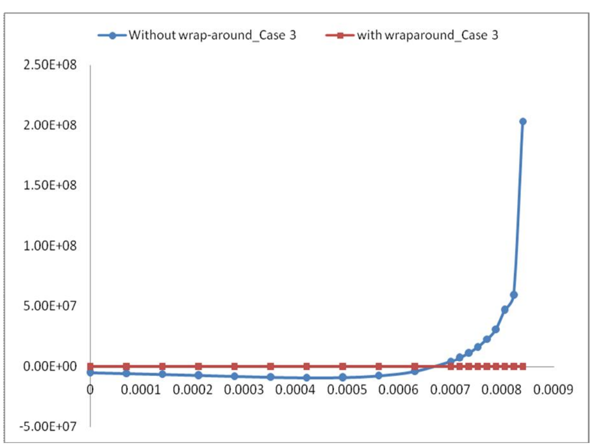

Figure 31: Distribution of the interlaminar normal Stresses along width case 3

Case 4: (+22/-22/90n)s, n=4

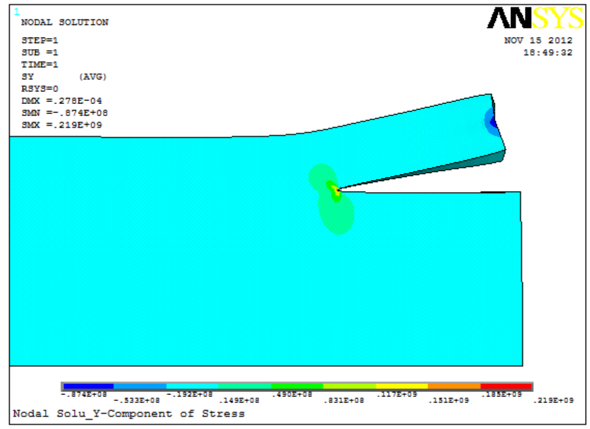

Figure 32: Contour of normal stress Delaminated model without wrap around case 4

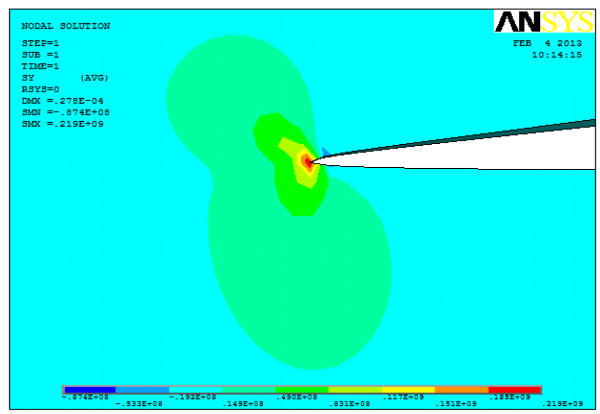

Figure 33: Variation of normal stress around the crack tip delaminated model without wrap-around Case 4

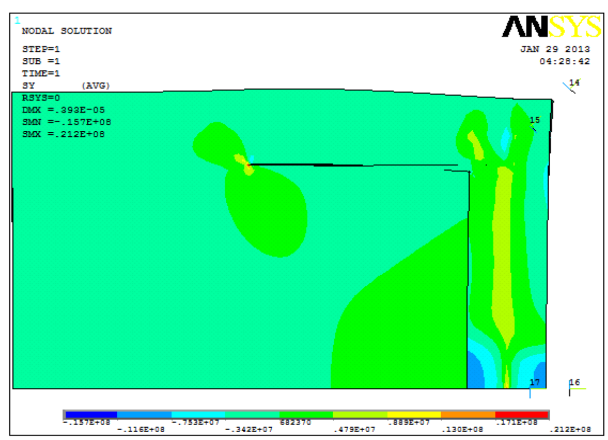

Figure 34: Contour of normal stress Delaminated model with wrap around Case 4

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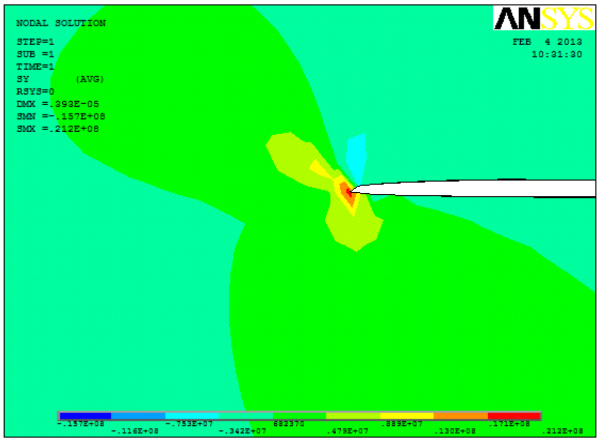

Figure 35: Variation of normal stress around the crack tip delaminated model with wrap-around Case 4

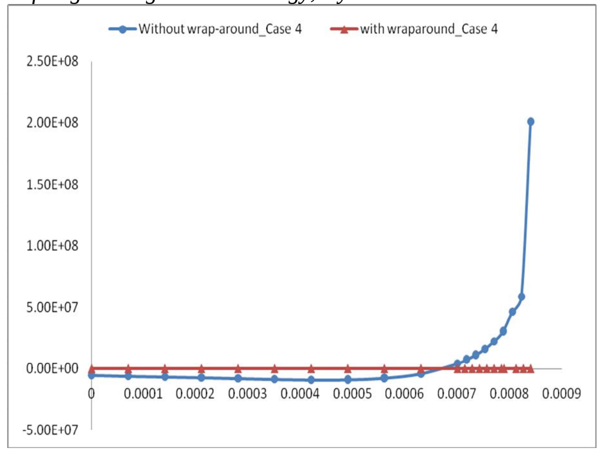

Figure 36: Distribution of the interlaminar normal Stresses along width case 4

Table 1: Value of Nodal Stresses at crack Tip

Case No.	Model Name	Interlaminar Normal Stress (MPa)	Interlaminar Shear Stress (MPa)
Case 1	Delaminated Model without wrap-around Case 1 (+22/-22/90n)s, n=1	1.97E+08	-4.99E+07
	Delaminated Model with wrap-around case 1 (+22/-22/90n)s, n=1	0.13309	-0.80830E+07
Case 2	Delaminated Model without wrap-around Case 2 (+22/-22/90n)s, n=2	2.01E+08	-5.38E+07
	Delaminated Model with wrap-around case 2 (+22/-22/90n)s, n=2	0.16350	-0.64286E+07
Case 3	Delaminated Model without wrap-around case 3 (+22/-22/90n)s, n=3	2.03E+08	-5.77E+07
	Delaminated Model with wrap-around case 3 (+22/-22/90n)s, n=3	0.15128	-0.65154E+07
Case 4	Delaminated Model without wrap-around Case 4 (+22/-22/90n)s, n=4	2.01E+08	-5.92E+07
	Delaminated Model with wrap-around case 4 (+22/-22/90n)s, n=4	0.15670	-0.15127E+08

Table 1 represents the average value of nodal stresses at crack tip for different eight models. From that value it is clear that interlaminar normal stress and interlaminar shear stress are reduced drastically by the help of wrap around method.

6. CONCLUSION:

Eight Models with and without wrap-around was investigated from a three dimensional finite element analysis to estimate the interface stress. The models are designed in ANSYS. Finite element analysis was performed on the models under uniaxial strain. The maximum interlaminar normal stress at crak tip was obtain from the finite element analysis.

From the stress analysis it is found that significant reduction of normal stress around crack is achieved by using wrap-around model.

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