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Performance of Nano Layers on Interlaminar Composite Laminate Strees

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Abstract:*This paper considers the variety of interlaminar stresses of composite plates with the nearness of delamination. The impact of an adjustment in the situation of delamination on the interfacial stresses is assessed. A four-layer composite overlay is produced for various stacking grouping and the interfacial stresses are acquired from the braced limit condition exposed to in plane pliable stacking. The target of the current work is accomplished by utilizing limited component based programming ANSYS. The variety of stresses in transverse and through thickness bearing, in plane and out of plane stresses is gotten from limited component models. The examinations uncovered that the nearness of delamination expands the interlaminar stresses. The solution for decline these burdens is proposed by choosing nano support. The current work gives an answer for smoother the impact brought about by interfacial stresses.*

Key words: *Interfacial Stresses, Stacking Sequence, Nano Reinforcement*

I. Introduction

High demand in the usage of composite material in aircraft, aerospace and transportation fields, encouraging the research to face many challenges in the design of these structures. The use of composite material replaced several conventional materials due to their high strength and high stiffness to weight ratio. Keeping aside the advantages of composites, the real performance of composite material depends on several factors such as delamination between the laminas, voids, cracks in the matrix phase, fiber failure.
[1]. Careful design of composite material may decrease the chances of failure. The failure of the laminate is obtained by first ply failure or ultimate laminate failure or interfacial stresses. Many authors dedicated their research time on the development of composite materials by considering above said problem.

A brief review of laminated plate theories was presented by Reddy and Robins for single layer and multilayer composite plates [2]. A comparative study on laminated theories is performed by Liu and Li [3] considering shear deformation theories, layer wise theories, generalized Zig-Zag theories. The vibrational analysis of composite laminated plates is obtained by Kim MJ and Gupta A by considering first- order shear deformation theory using finite element approach.[4].

Damage in laminated composite with open hole subjected to compressive loading and in-plane loading was studied from initial loading to final failure by Chang and Lessard [5]. A progressive failure model for predicting the accumulated damage and the effect of the same damage under in-plane loading of laminated composite subjected to tensile and shear loads are discussed by Sahid and Chang [6]. One of the failure indications of laminated composite is first-ply failure. The first-ply failure load in both linear and geometrically nonlinear stage of thin and thick composite plates subjected to uniformly distributed transverse load was performed by Reddy YSN, Reddy JN [7]. The failure mechanism and ultimate failure loads of the cross-ply and quasi-isotropic laminates for different stacking sequences subjected to axial extension was conducted by Joo SG, Hong CS with generalized plate theory [8]. On the other side, the application of carbon and their derivative nanotube are increasing in composite material to further strengthen their performance. Fracture toughness of carbon fabric reinforced polymer laminates can be improved by adding multi-walled carbon nanotubes. [9]. The performance of hybrid composites obtained by reinforcing glass fiber, carbon fiber in an epoxy matrix along with nano filleres such as graphine, multi wall carbon nanotubes are performed by Shivakumar Gouda et al.[10]. p.prasanthi et al used Buckminster fullerene nano reinforcement to obtain the effectiveness of nano reinforcement in regular composites. [11]. Few studies are focused on the positive effect of carbon nanotube filling on the propagation resistance of polymer resin. [12-13].

From the above literature survey, it is observed that, composite materials performance is depends can be enhanced with nano reinforcement. The present research work is focused on the effectiveness of carbon nanotube reinforced composite lamina on the regular fiber reinforced composite laminate. The work is planned in three phases. The first phase of the work is focused on the determination of interfacial stresses of composite plate with proper modeling and validation. In the second phase, the work is concentrated on the effect of delamination on the interlaminar stresses. In the last phase the effectiveness of cnt laminas on the performance of composite laminate is studied from the perspective of interlaminar stresses.

II. Finite Element Modeling

The finite element model is generated by using selecting layered 46 element of Ansys. This element is defined by 8 nodes and each node has three degrees of freedom in translation in the nodal x ,y and z directions. The element allows up to 250 different material layers. Fig.1. shows the shape of the element of layered 46.

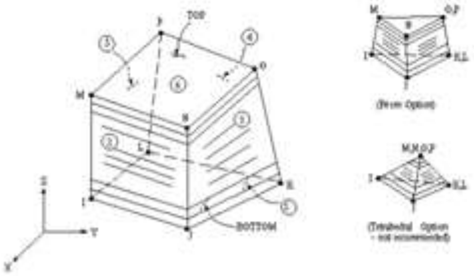
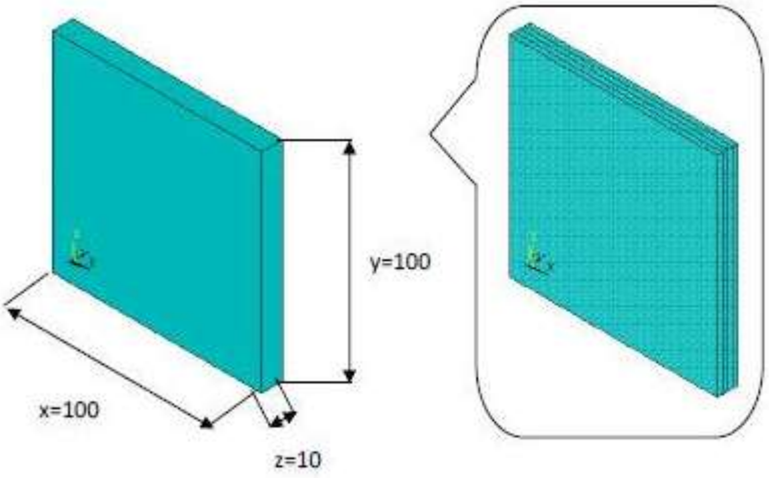


Figure 1 SOLID46 3-D Layered Structural Solid [15]

2.1 Geometry: The geometry of the finite element model was of rectangular shape with a width (x) and height (y) of 100 mm, and thickness of 10 mm. Each laminate is packed with four laminas with five different stacking sequences of [0/90/90/0], [0/45/-45/0], [30/-30/30/-30]. [15/-15/15/-15] and [60/-60/60/-60]. Fig. 2.a and b show the geometrical model and two of stacking sequences considered for the present work.



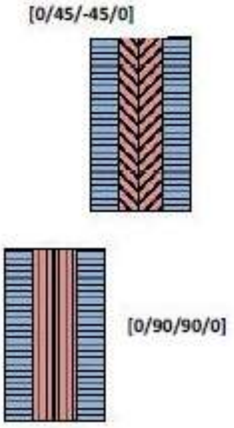
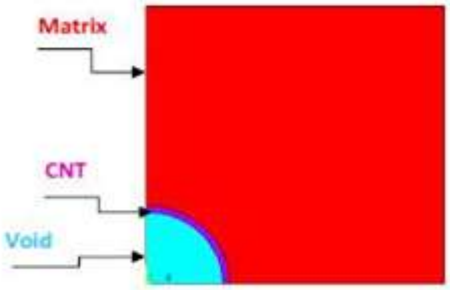


Fig.2.a Geometrical Model **Fig.2.b** Laminas in the thickness direction

2.2 Material Properties: The composite laminate is made of unidirectional E glass epoxy. The properties required for the present analysis are obtained from Table.1. The carbon nanotube reinforced composite properties are obtained from Micromechanics approach at 0.1 volume fraction of Carbon Nanotube. E_1= 67.64GPa, E_2=14.24GPa, E3=14.24GPa ν_{12}=0.33, ν_{13}=0.33 ν_{21}= 0.07. The mythology obtained for obtaining the CNT reinforced composite is same as discussed in [11 and 16]. Fig.3.and 4 show the geometry and loading applied on finite element models.



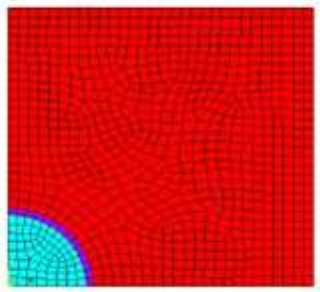
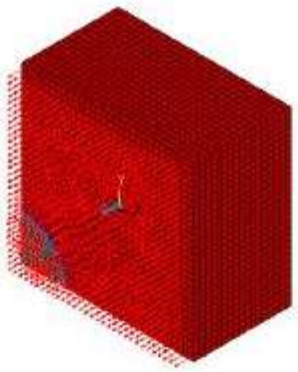


Fig.3.a Geometrical model at 2% volume fraction **Fig.3.b** FE meshed model at 2% V_{cnt}



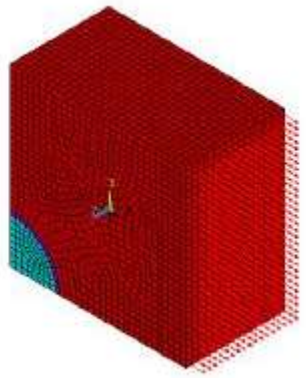


Fig.3.c Longitudinal load on the CNT composite **Fig.3.d** Transverse load on the CNT

To get E_1 and v_{12} composite to get E_2 and v_{21}

Table.1. Material Properties

Property	**Eglass epoxy** [14]
Fiber Volume fraction	0.55
Longitudinal Modulus, E1, (GPa)	41
Transverse in-plane Modulus, E2, (GPa)	10.4
Transverse out- of-plane modulus, E3, (GPa)	10.4
In-plane shear modulus, G12, (GPa)	4.3
Out-of-plane shear modulus, G23, (GPa)	3.5
Out-of-plane shear modulus, G13, (GPa)	4.3
Major-in-plane Poisson's ratio, v12	0.28
Out-of-plane Poisson's ratio, v23	0.50
Out-of-plane Poisson's ratio, v13	0.28

2.3 Loading and boundary conditions: The interlaminar stresses are obtained for fixed boundary condition of a composite plate. All the sides of the composite plate are fixed in all aspects as shown in the following Fig. [4]. A pressure load of 1Mpa is applied to the positive in-plane of the composite laminate [5].

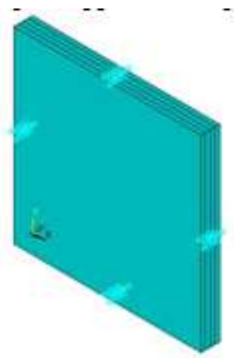


Figure 4 Boundary condition of the composite laminate **Fig.5.** Unifrom Pressure load on the laminate

2.4 Validation: The methodology adopted for the present element model is validated by comparing the transverse deflection of composite plate with published work. The transverse defection of the composite plate is obtained by considering $[0/90]_4$ sequence for different a/h ratio (side dimensions of the plate/ thickness of the plate with E1/E2=25, G12=G13=5GPa, G23=2 GPa. The following table shows the correlation between the published data and current results.

Table.1 Comparision of transverse deflection of composite plate with published work

a/h	Present work (mm)	Reddy (1997) (mm)
10	0.9892	0.9519
20	0.7531	0.7262

III. Results And Discussion

Ensuring proper modelling, validation of finite element models, the maximum inter laminar stresses of composite laminate are obtained by applying above mentioned stacking sequence, loading and boundary conditions. As an example, Consider a cross-ply laminate $[0/90]_s$, consists of four plies having unidirectional fibers subjected to in-plane pressure (x-y plane). For unidirectional lamina, longitudinal modulus E_1 is much greater than E_2.

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As the laminate subjected in- plane loading, both 0 and 90^0 lamina is equally strained in the xy plane. Due to unequal properties in longitudinal, transverse direction 0^0 laminae will contract more than the 90^0 lamina in the y-direction. As a result, more stresses are generated in y-direction than the x-direction. The same concept is observed from Fig.6-7. Compared to normal stresses (x and y) through thickness stresses are minimum in all the cases (Fig.8). The laminate offers more resistance in the direction parallel to the laminas i.e. in plane direction.

Fig.9-11 show the variation of in-plane, out-of-plane shear stresses for different ply sequences. The in-plane shear stresses are more for [30/-30/30/-30] and [60/-60/60/-60] sequences. From these Figures, it is observed that the composite laminnate made of these lay-ups may prone to produce debonding between the layers of the composite laminate.

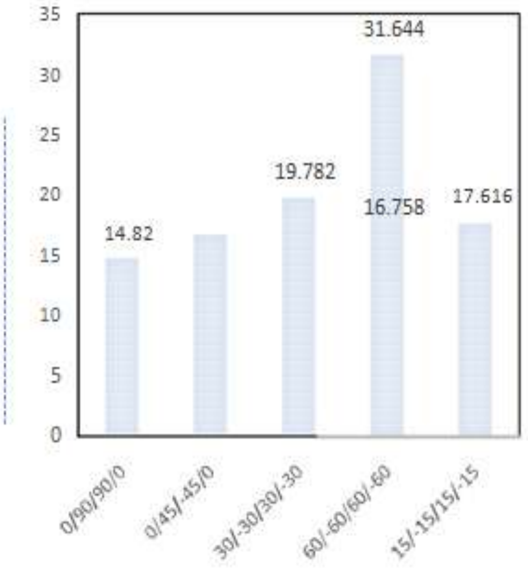


Fig.6. Variation of Nor mal stresses (σ_x)

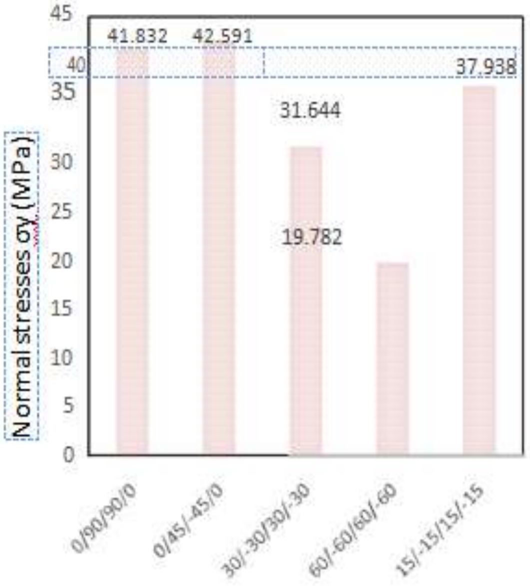


Fig.7. Variation of Norrmal stresses (σ_y)

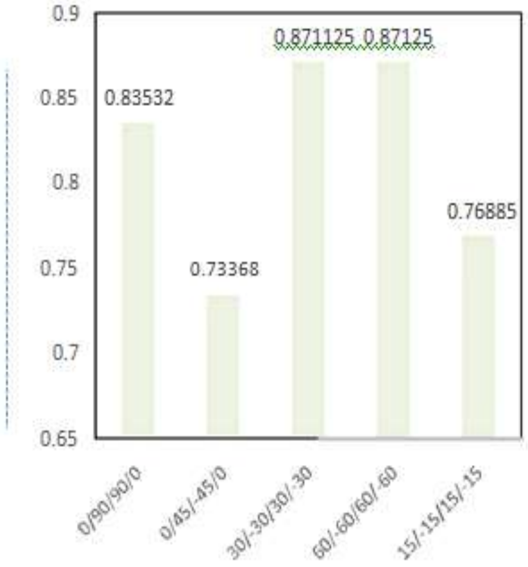


Fig.8. Variation of Through thickness stresses (σ_z)

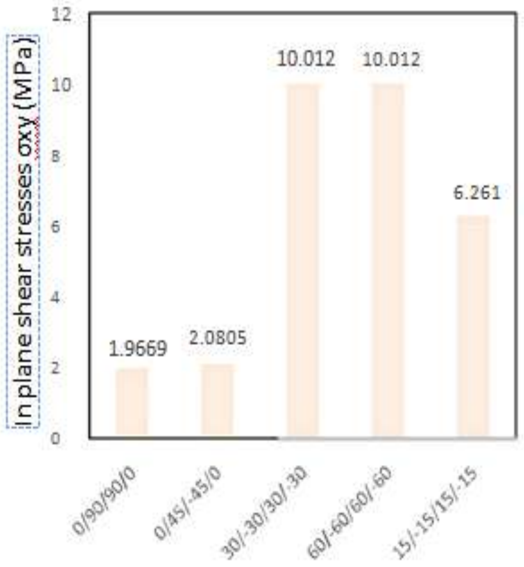
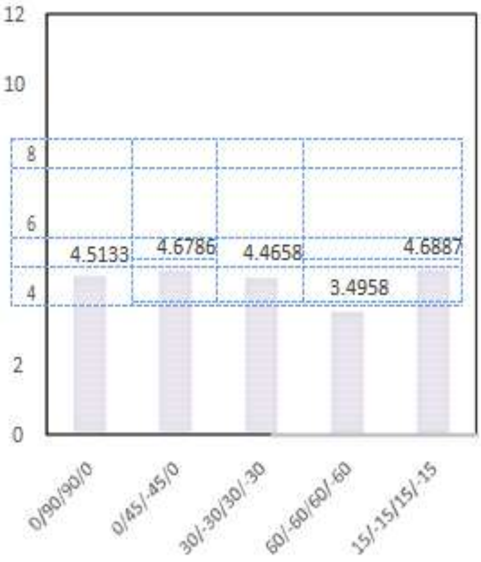


Fig.9. Variation of in-plane shear stresses (σ_{xy})



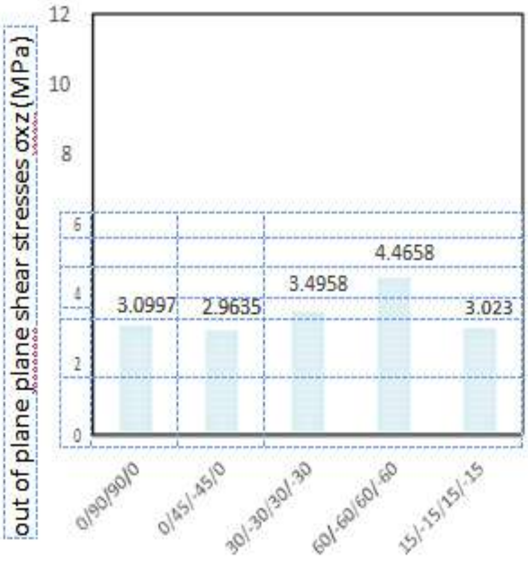
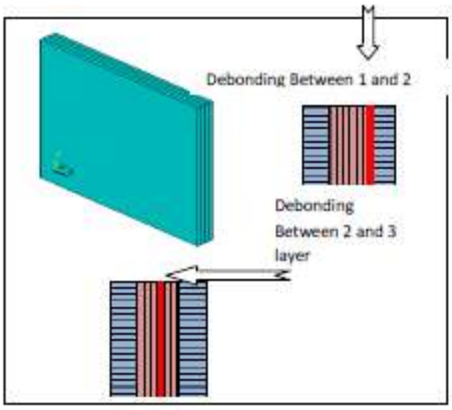


Fig.10. Variation of out-of-planne shear stresses (σ_{yz}) **Fig.11.** Variation of out-of-plane shear stresses (σ_{xz})

IV. Effect Of Delamination And Effectiveness O F Carbon Nanotube Reinfroce Ment

High interfacial stresses in the composite laminate may leads to the delamination. Delamination is failure in a laminated material, often a composite, which leads to separation of the layers of reinforcement or plies. In this section the effect of delamination on the interfacial stresses is highlighted by varying the position of delamination and a method to decrease these interlaminar stresses are proposed by opting carbon nanotube reinforced comp osite layers.

A hybrid composite laminatee is generated by placing a nano cnt reinforced composite lamina in between the regular composite l aminas. The following Fig.12 a and b. show the arrangement of nano layers in a laminate. The hybrid composite plate is prepared with same dimension of composite plate as shown in the Figure.3. In order t o place CNT lamina, the regular composite lamina size is decreased. In this each lamina having thickness of 2mm and CNT layer thickness is 0.6666mmm. The width and height of the plate are same as that of the regular composite plate.



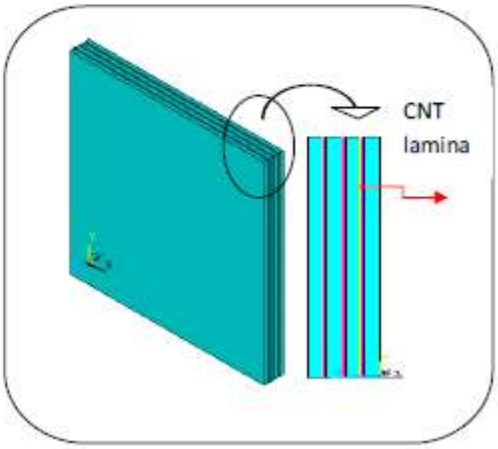


Fig.12. a Delamination of the layers in the laminate **Fig.12.b** Geometrical model of Hybrid composite

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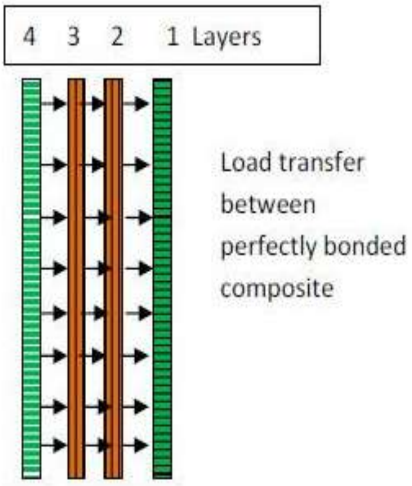
The loading and boundary condition applied to the hybrid composite is same as that applied on a conventional composite plate. The analysis is performed under three different situations. The first part is focused on the evaluation of interfacial stresses of a composite plate with delamination between the first and second layers. The second case study is dedicated to the effect of delamination by changing the position from the second and third lamina. In the final phase of work, the remedy to decrease the interfacial stresses are suggested by changing the regular composite to hybrid composite. The hybrid composite is prepared by placing a CNT induced polymer layer in between the composite laminas. Fig.13. a and b. show the transformation of interlaminar stresses under perfect and imperfect bonding conditions.



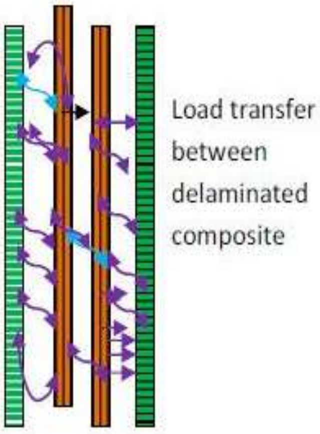
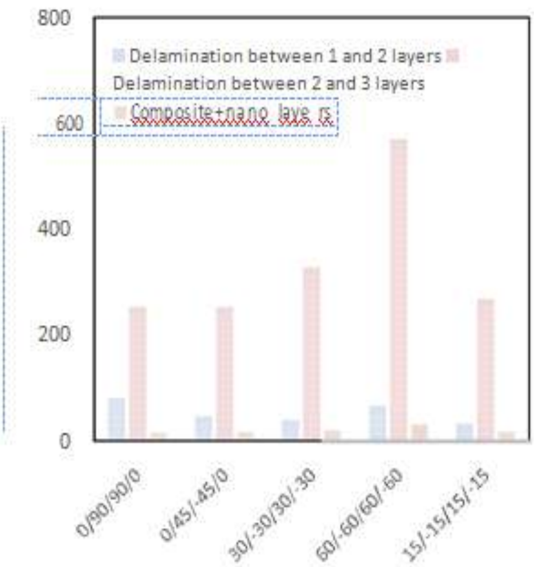


Fig.13.a. Stress transformation under perfect bonding **Fig.13.a.** Stress transformation under imperfect bonding

The interfacial stresses increase in all the cases due to delamination. Compared to delamination at 1 and 2 layers, the effect of delamination on interfacial stresses is high in case two i.e delamination at 2 and 3 layers. The load acting on the composite plate is transmitted from layer four to layer one through layer three and two. For effective transmission of load among the layers there should be perfect a bonding between the layers. Because of the delamination between two and three layers, the load taken by the third layer from fourth layer will not be able to transmit full load received from fourth layer. As a result, high interfacial stresses will be generated. The severity of these stresses is decreased by moving away from the layer which is subjected to load.

One of the method is proposed by current authors is that by placing a hybrid composite instead of conventional composite, the influence of interfacial stresses can be decreased under real application of composite structure. This could be well understood from the Fig. 14-19. One of the causes to the formation of delamination is that concentration of high intensity interfacial stresses. The delamination of layers may cause to the failure of the composite structure. The proposed work will try to minimize these interfacial stresses by taking the advantage of carbon nanotubes. Reinforcing carbon nanotubes in a polymer matrix, the properties of matrix material can be enhanced.[11]. By placing these layers in between, the composite layers, one can decrease the failure of the composite structure due to debonding and high interfacial stresses. The results are encouraging in the cases, i.e all the stacking sequences considered for the analysis.



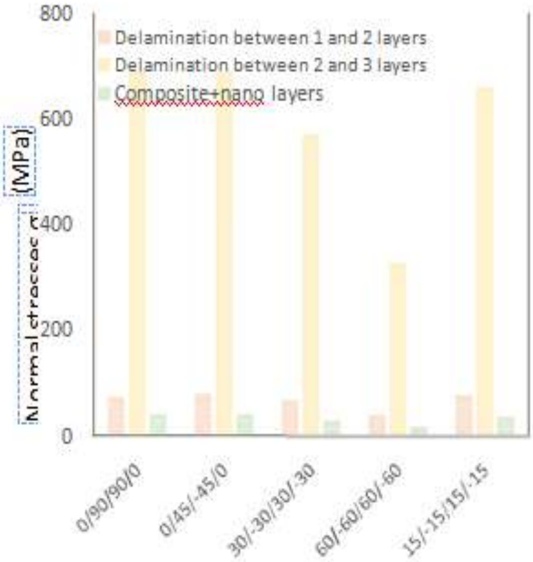
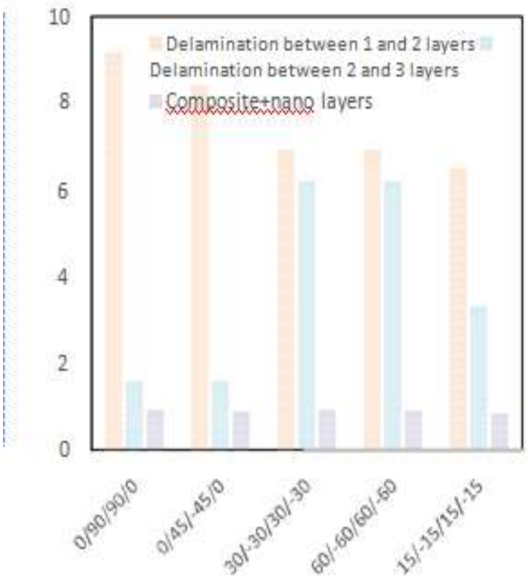


Fig.14. Variation of σ_x (MPa) w ith delamination

Fig.15. Variation of σ_y (MPa) with delamination



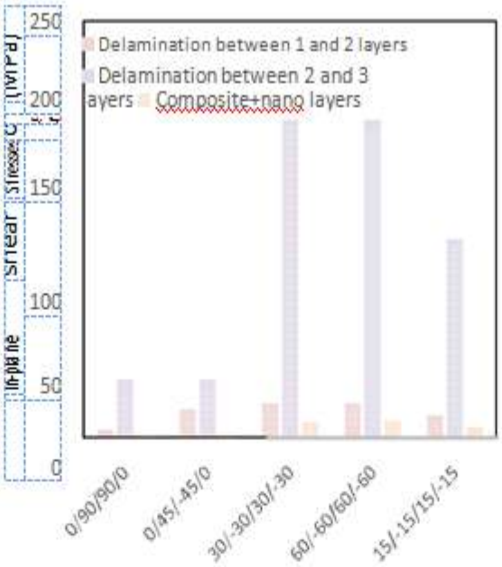


Fig.16. Variation of σ_z (MPa) w ith delamination

Fig.17. Variation of σ_z (MPa) with delamination

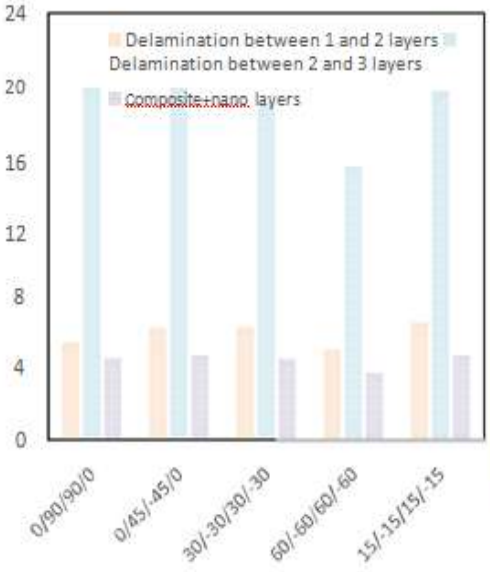


Fig.18. Variation of σ_{yz} (MPa) with delamination

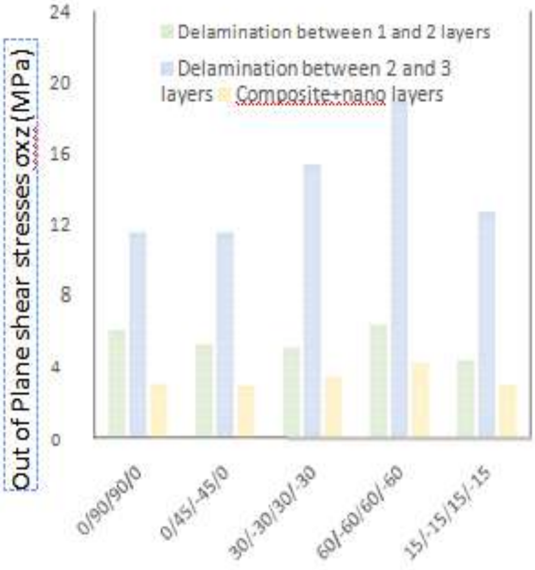


Fig.19. Variation off σ_{xz} (MPa) with delamination

V. Conclusions

A finite element model has been proposed to simulate the interlaminar stresses of composite laminate with delamination. Later the effectiveness of carbon nanotube reinforced composite laminate to decrease the interlaminar stresses is proposed . The presence of delamination develops high intensity interlaminar stresses. The intensity of these stresses can be decreased by placing a nanotube reinforced composite lamina. The present work is used for effective design of hybrid composites.

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