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Computational Investigation of through the Width Delamination of a Composite Laminate using VCCT

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Abstract: The fiber reinforced polymer laminates have found extensive applications because of its advantages over other materials in terms of strength, stiffness, stability, weight saving features, resistance to corrosion and erosion and many more. But due to poor transverse direction strength, a failure mechanism called delamination will occur in case of poor manufacturing or when tools are dropped which would make an impact.
In this paper, VCCT is implemented at the interface between base and sub laminate to investigate for 20mm through the width buckling driven delamination growth.
The computational prediction of delamination growth initiation is obtained by solving a T300/976 specimen for geometric non linearity using SC8R continuum shell elements of Abaqus CAE and by plotting the required energy release rate at the edge of delamination geometry.
Keywords: Through width delamination, VCCT, uniaxial compression, B-K criterion, energy release rate.

I. INTRODUCTION

The failure mechanisms of an FRP are fiber bridging, fiber pullout, matrix cracking, matrix debonding, delamination, kink band and micro buckling. And the focus of this paper is on interface delamination due to uniaxial compressive loads. Delaminations are known to decrease the overall strength and stiffness of the specimen which reduces the load bearing capacity under compressive loads.

The causes of delamination are In-service loads, Impact, cut outs, Load generating transverse stresses, notch, bonded joints, Material and structural discontinuities and plydrop. Comparatively the interface is weaker in the transverse direction which will lead to high transverse and normal stresses which would induce interlaminar stresses that would lead to separation of layers. Therefore the interface is weaker compared to that of other directions of plies. Hence it is necessary to predict the delamination initiation growth using damage tolerance technique [1].

II. LITERATURE SURVEY

Early works were done Chai et al for 1D and 2D problems [2][3]. Whitcomb and Shivakumar inspected the delamination growth due to the local buckling of a composite plate with square and rectangular embedded delaminations [1]. Nilsson et al. studied delamination buckling and growth of slender composite panels using both numerical and experimental methods [4]. Riccio et al. studied the compressive behavior of carbon fiber/epoxy laminated composite panels containing through the width and embedded delaminations [5]. Lachaud et al. used the VCC integral to investigate the propagation of delamination caused by the local buckling, on thermoset and thermoplastic carbon/ fiber composite laminates having embedded delaminations. They also conducted experiments to verify the obtained results from the simulation[6].

III. METHODOLOGY

The computation is carried out by virtual crack closure technique (VCCT) whose assumption is that the energy required for a crack in its existing configuration to its next configuration and then next to its' extended configuration is the same energy required to close the crack and bring it back to its initial configuration as shown in Fig 1and 2 [7]. This technique is based on Irwin's crack closure method. the work ΔE required to close the crack along one element side can be calculated as

$$\Delta \mathbf{E} = \frac{1}{2}[\mathbf{X1l}.\Delta \mathbf{u_{2l}} + \mathbf{Z1l}.\Delta \mathbf{w_{2l}}]$$

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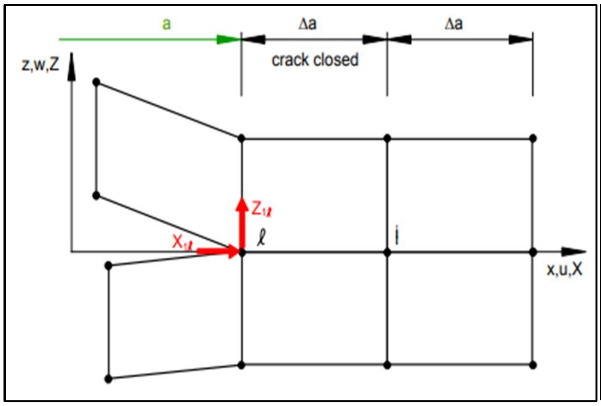

Fig 1: First step crack closed

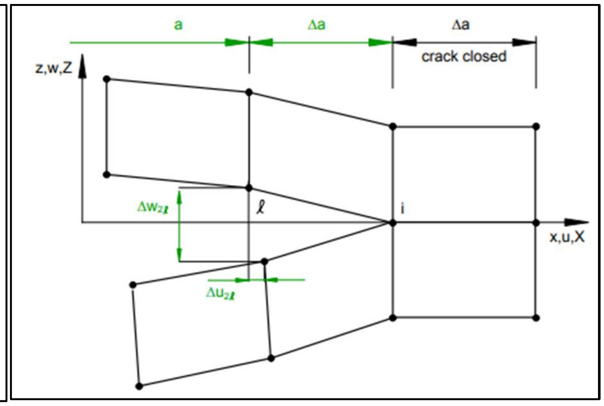

Fig 2: Second step crack extended

where X_{1l} and Z_{1l} are the shear and opening forces at nodal point l which gets closed and Δu_{2l} and Δw_{2l} are the shear and opening nodal movements at node l.

The energy release rate is calculated as $G=\Delta E/\Delta A$, where ΔA is the surface area of the newly formed crack extension.

For delamination growth initiation, B-K criterion is applied [9].

In real time problems, delamination growth occurs due to energy release rates in all 3 directions namely normal and 2 shear directions. Hence total energy release rate is given by $G_T=G_I+G_{II}+G_{III}$ and the nodes open up and propagates when the condition $G_T/G_C\geq 1$ is satisfied, where critical energy release rate is found by B-K criterion that has contribution from all 3 modes given by $G_C=G_{IC}+(G_{IIC}-G_{IC})(G_S/G_T)^{\eta}$, where $G_S=G_{II}+G_{III}$.

Now a specimen having unidirectional stacking sequence of $[0_4 / 0_{12} // 0_4]$ is considered which is made of the T300/976 as in [3]. The symbol // illustrates pre-delamination location in the material. The geometry of specimen with single delamination is shown in the Fig. 1. The material properties of T300/976 are E_{11}=139300 (N/mm2), $E_{22}=E_{33}$=9720 (N/mm2), $G_{12}=G_{13}$=5580 (N/mm2), G_{23}=3450 (N/mm2), $\nu_{12}=\nu_{13}$=0.29, ν_{23}=0.4, G_{IC}=0.0876, G_{IIC}=0.3152 (N/mm), σ_o = 44.54 (N/mm2), τ_o = 106.9 (N/mm2). Thickness of each lamina=0.129mm and the total thickness of the laminate is h=2.58mm as shown in the Fig [8].

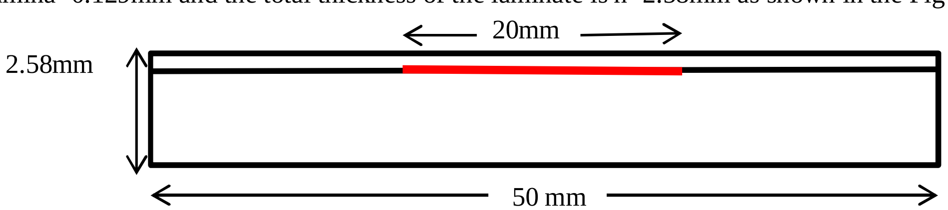

Fig 3: Illustration of the specimen

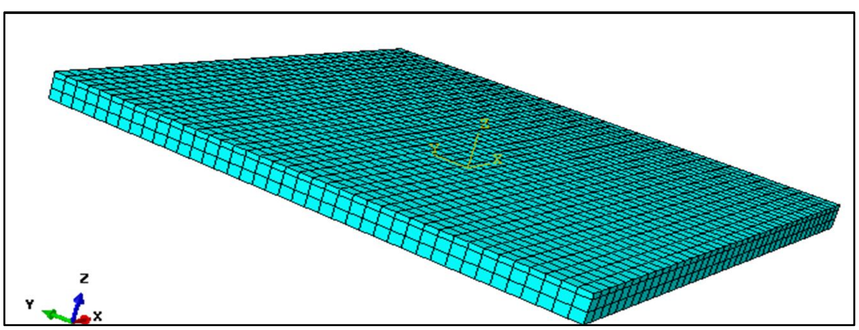

Fig 4: Meshed plate

The above Fig shows the meshed plate of the specimen whose boundary conditions are u1=u2=u3=ur1=ur2=ur3=0 on the left extreme side and u2=u3=ur1=ur2=ur3=0 on the right side with a compressive load of u1=0.30819mm is applied for the first step as that was the buckling load obtained in terms of displacement. And for the second step, 1.5mm is applied.

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IV. RESULTS AND DISCUSSION

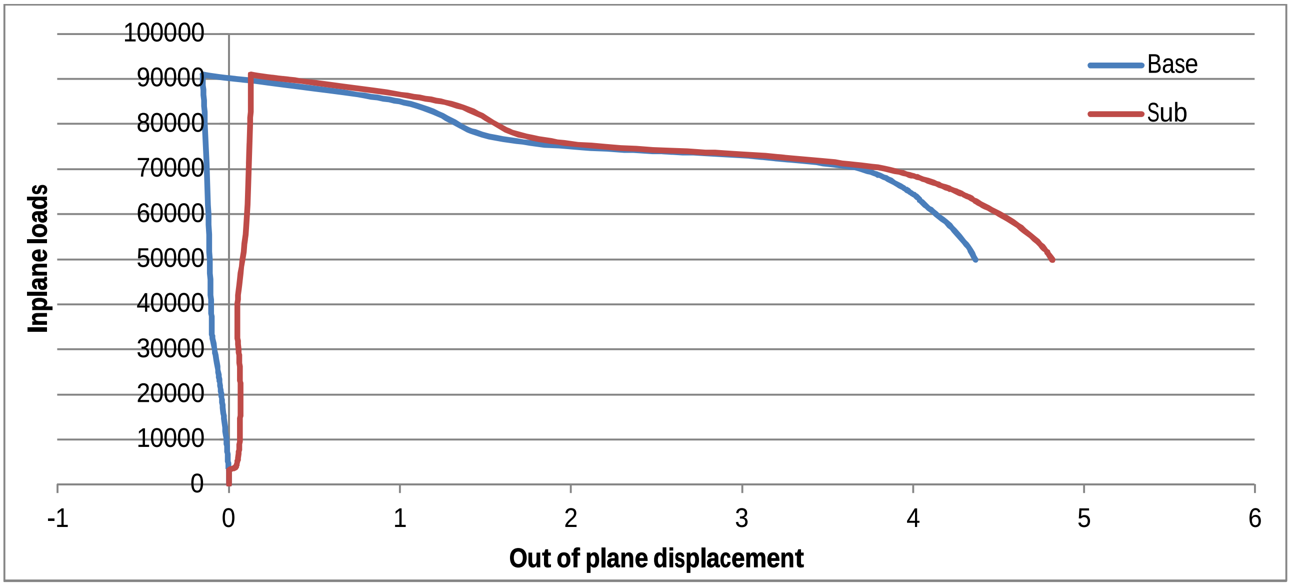

Fig 5: Inplane loads vs Out of plane displacements

Inplane loads at the left support versus out of plane displacements at the centre of the base and sublaminate is plotted as shown in Fig 5. From the plot it can be clearly observed that buckling occurs at 165N. Local buckling can be observed at 3.40KN. The initial post-buckling response is ruled by the buckling of the thinner sub-laminate alone which is known as thin-film buckling. Postbuckling behaviour can be either stable or unstable. In this analysis, stable post-buckling and local buckling occurs at the delamination growth initiation later the shape changes to an opening mode shape occurs at 90.97KN and then the shape shifts to a state where the top and the bottom of base and sub-laminates contact each other at 72.93KN. This situation is also known as overall buckling. And afterwards slowly the laminate collapses.

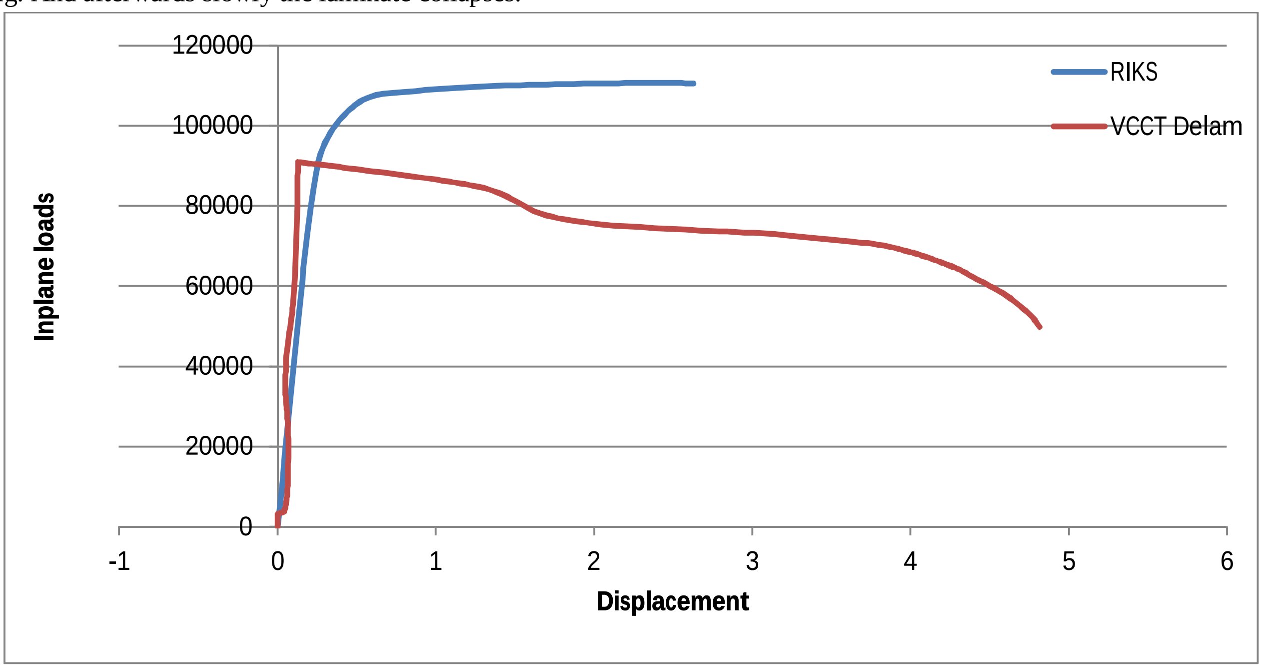

Fig 6: Inplane loads vs Out of plane displacement

Fig 6 shows plot of inplane loads versus out of plane displacement of the specimen considered in this paper by RIKS method and Delamination using VCCT. It is clear that the overall load carrying capability has reduced considerably which is about 110KN before collapse.

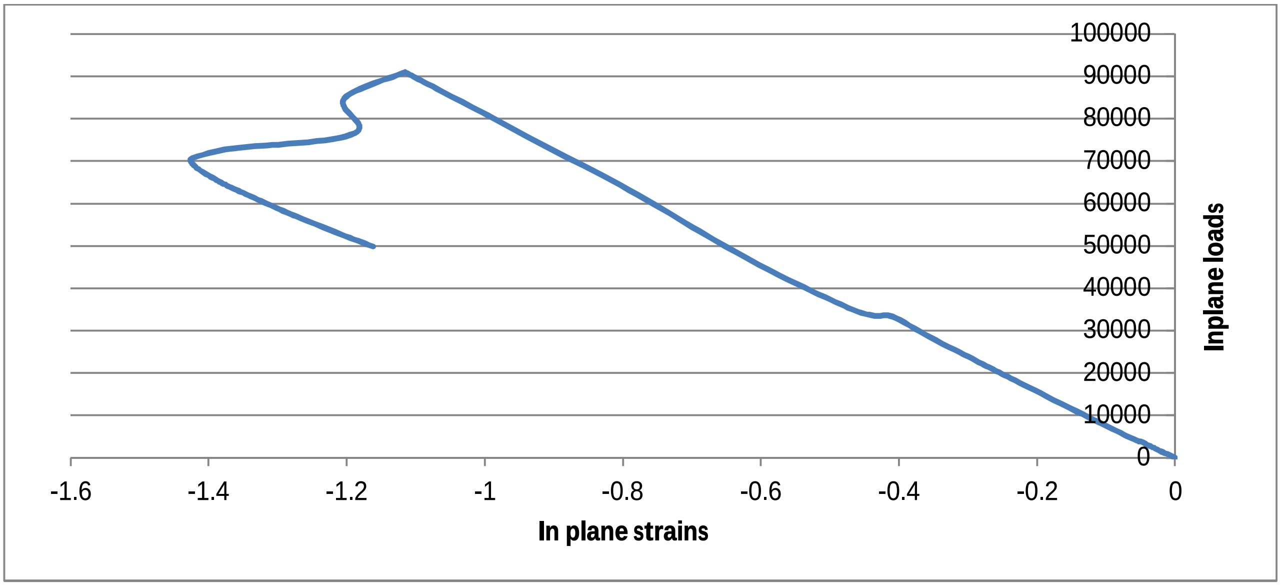

Fig 7: Inplane loads vs Inplane strains

The above Fig 6 shows the behavior of the specimen in which inplane loads versus inplane strains is plotted in which local buckling can be clearly seen at 3.4KN followed by opening mode shape at 90.97KN and with the propagation of delamination the surfaces of base and sub laminates contact each other at 72.93KN.

V. CONCLUSION

In this paper a specimen considered from [8] is analyzed computationally using VCCT in ABAQUS CAE. From the analysis, buckling, post buckling using both RIKS and VCCT has been observed and compared for reduction in load carrying capacity followed by damage evolution and the transitions made by base and sub laminates so that local buckling, opening mode delamination followed by overall buckling were observed.

VI. ACKNOWLEDGEMENT

I thank my family and almighty for everything.

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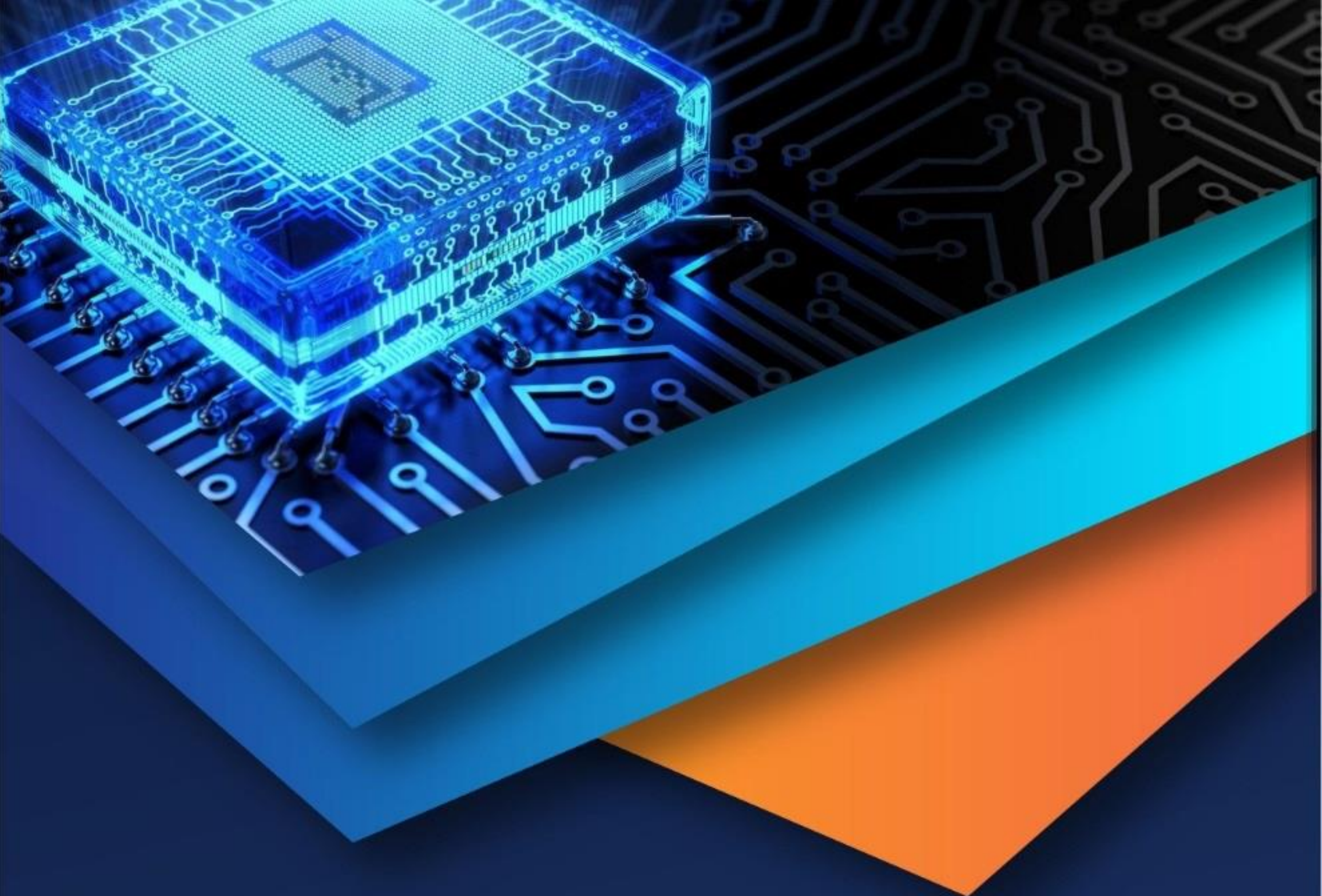

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