COMPUTATIONAL INVESTIGATION OF MULTIPLE CIRCULAR EMBEDDED DELAMINATIONS DESCENDING FROM TOP OF A COMPOSITE LAMINATE USING VCCT

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Abstract - The Carbon Fiber Reinforces Polymer (CFRP) composite laminates have extensive applications in Aviation and Aerospace industry as they have many advantages over other materials in certain material parameters, design and manufacturing such as strength to weight ratio, thrust to weight ratio, resistance towards corrosion and erosion, tailoring, temperature effects and so on. The interface regions in transverse direction between each lamina have less strength compared to longitudinal and lateral directions of the plies that would lead to one of the failure mechanism called delamination which might occur due to impact loads as in case when tools are dropped, due to poor manufacturing, slag and so on. In this paper, VCCT is employed at the interfaces using Abaqus software between base and sub laminates to investigate for multiple circular shape delamination geometries of 30mm, 44mm and 60mm at various depths subjected to buckling driven delamination growth from the top. The investigation is done for geometric non linearity condition and frictionless tangential behavior by implementing SC8R (continuum shell elements) elements in the CAE software Abaqus.

***Key Words*:** Circular embedded multiple delaminations, VCCT, uniaxial compression, B-K criterion, energy release rate.

1. Introduction

The laminated composite materials have observed to fail due to fiber pullout, barely visible impact damage (BVID), matrix debonding, fiber bridging, buckling delamination, matrix cracking, micro buckling, high velocity impact, low velocity impact and kink bands. Basically Delaminations have been known to decrease the stiffnes, overall stability and strength of the specimen which would reduce the capacity of withstanding the itself under compressive loads. It is known that the causes of delamination are service loads ,Impact and loads generating transverse stresses at locations such as Material and structural discontinuities, cut outs, notch, plydrop and bonded joints. And Delaminations are caused since the interface is relatively weaker in the transverse direction in comparison to that of the strength of plies, that would give rise to high normal and shear stresses at the interface leading to separation of layers. Therefore it is an important requirement to calculate the delamination initiation growth with multiple delaminations using damage tolerance technique by VCCT (MVCCI) [1].

Preliminary works were completed by Chai et al for 2D and 1D problems [2][3]. Whitcomb and Shivakumar studied the delamination evolution due to the local buckling of a composite plate with square and rectangular embedded delaminations [1]. Nilsson et al. investigated delamination growth and buckling of composite slender panels using numerical and experimental methods [4]. Riccio et al. examined the compressive behavior of carbon fiber/epoxy laminated composite panels containing embedded and through width delaminations [5]. Lachaud et al. considered the VCC integral to explore the propagation of delamination instigated by the local buckling, on thermoset and thermoplastic carbon/ fiber composite laminates having embedded delaminations. They also showed many experiments to authenticate the accomplished outcomes from the simulations [6]. So there is a requirement to solve the problem of embedded delamination by damage tolerance technique. Hence the work carried out in this paper focus on multiple interface delaminations due to uniaxial compressive loads.

2. Methodology

The computational work is executed in Abaqus software using VCCT technique which theoretically is MVCCI technique. And according to MVCCI technique, the energy essential for a crack in the present configuration to its extended configuration and further next to its' extended configuration is the approxiamately same energy that is required to close that crack and to make it back to its initial configuration when the process started with no changes in stress considerably as shown in Fig 1and 2 [7]. This procedure is modified from Irwin's crack closure method which is a two-step process. The workdone necessary to open the crack along the damage direction as shownin figure 2 can be calculated as

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

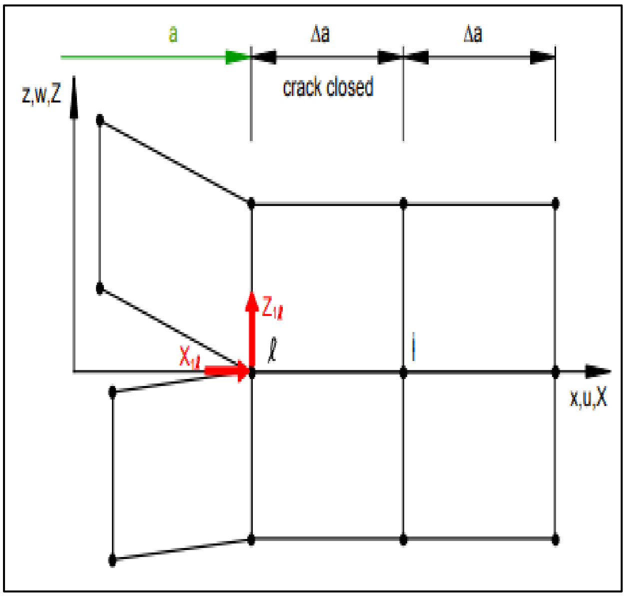

Fig -1: First step crack closed

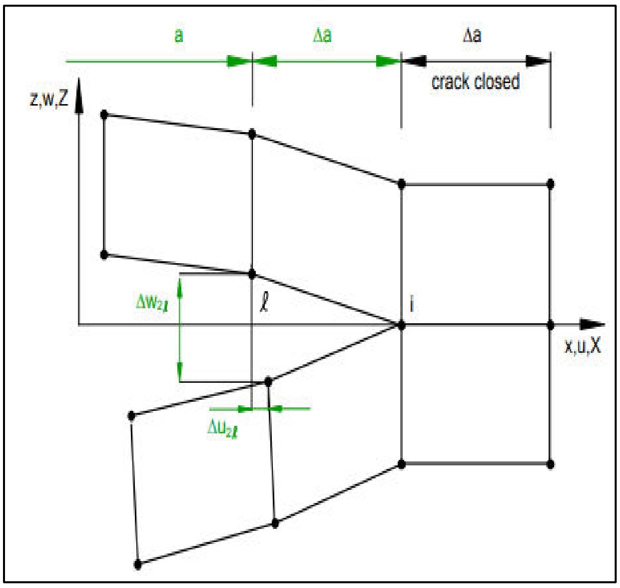

Fig -2: Second step crack extended

Where Z_{1l} and X_{1l} are the opening forces and shearing forces at the reference node l and Δw_{2l} and Δu_{2l} are the opening forces and shear forces 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 the onset and growth of delamination, BK Criterion (Benezeggagh-Kenane criterion) for mixed mode behaviour is employed [9][10][11].

Hence total energy release rate is given by $G_T=G_I+G_{II}+G_{III}$ and the nodes open up and the damage 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 $[0/90/0//0/90/0//0/90/0//0/(90/0)_6]$ ie. 22 layer laminate is considered which is made of the CFRP as in [8]. The location of delamination geometry is shown by the symbol // at various depths implying multiple delaminations in the material. The geometry of the multiple delaminations is shown in the figure 3. The material properties of CFRP are E_{11}=139400 (N/mm2), $E_{22}=E_{33}$=10160 (N/mm2), $G_{12}=G_{13}$=4600 (N/mm2), G_{23}=3500 (N/mm2), $\nu_{12}=\nu_{13}$=0.3, ν_{23}=0.43, G_{IC}=0.3, G_{IIC}=0.48 (J/m^2). Thickness of each lamina=0.18mm and the total thickness of the laminate is h=3.96mm as shown in the Fig 3 [8] with delamination dimensions 60mm, 44mm and 30mm respectively from the top. The imperfection factor used is 0.05.

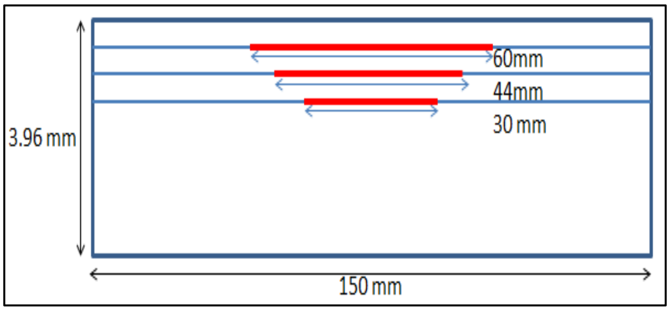

Fig -3: Illustration of the specimen

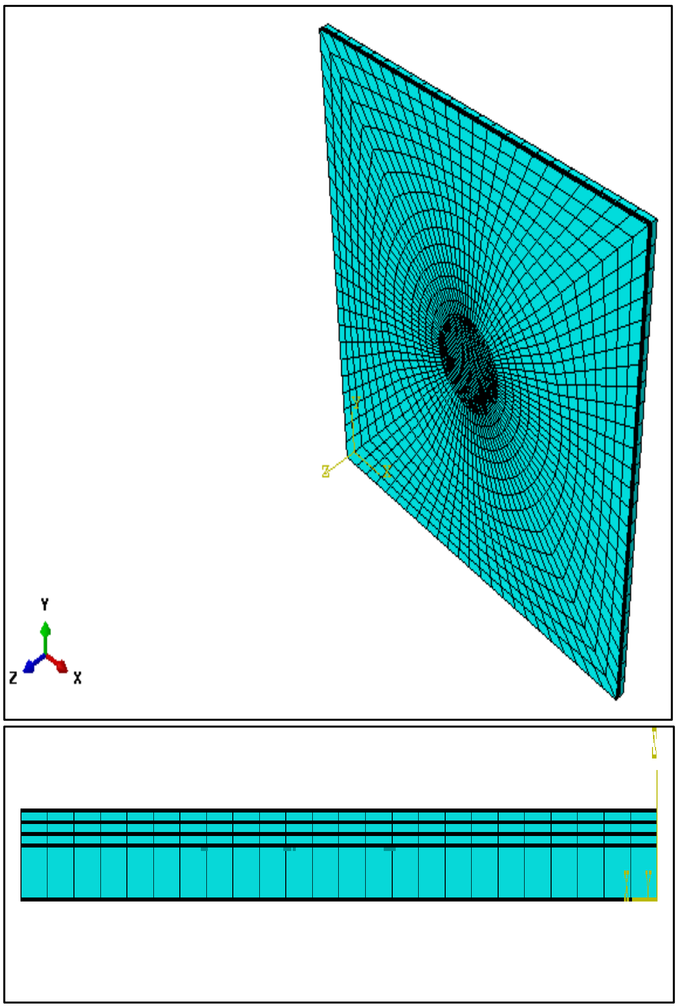

Fig -4: Meshed plate

The above Fig shows the meshed plate of the specimen whose boundary conditions are u1=u2=u3=0 on the top and bottom sides with a finite displacement value of 0.5mm and 1.5mm applied as compressive displacement loads at the bottom in terms of a two-step analysis and u3=0 on the right and left sides.

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3. Results & Discussion

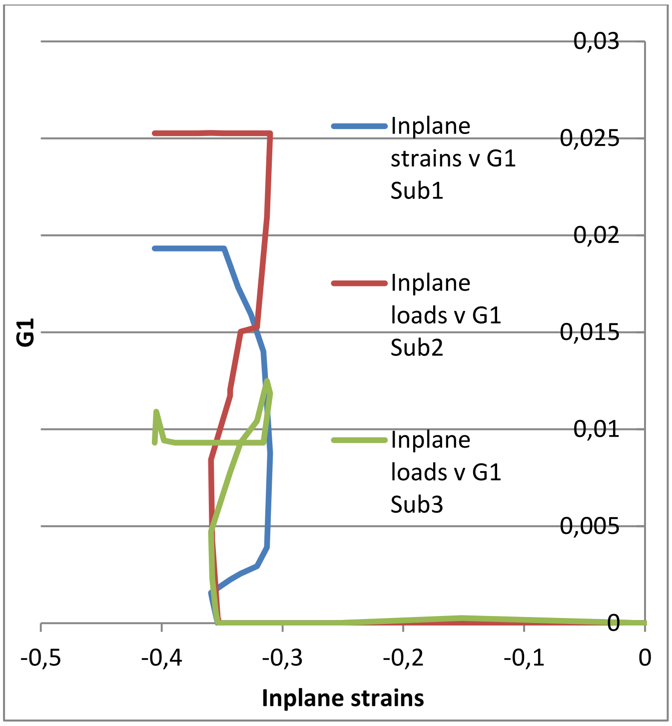

Fig -5: Mode I SERR vs Inplane compressive strains

In the figure mode 1strain energy release rate G1 (SERR) versus inplane compressive strains is plotted for the CFRP laminate considered from [8] (figure 5). From the plot it can be clearly observed that mode 1 strain energy release rate follows a sudden curved vertical variation and horizontal smooth variations at 0.025 J/m^2, 0.0195J/m2 and 0.0125J/m2 for sublaminates 1, 2 and 3 respectively.

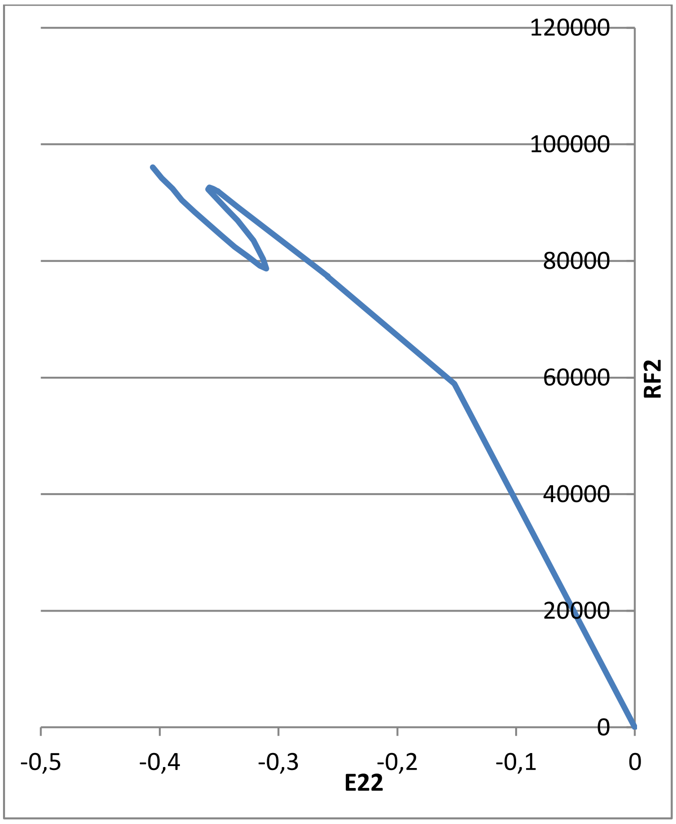

Fig -6: Inplane loads vs Inplane strains

The above figure 6 shows the behavior of the specimen in which inplane loads versus inplane strains is plotted. From the figure it is evident that the load required by the laminate to initiate delamination under room temperature is about 92KN and the load drops to 78.5KN due to delamination growth.

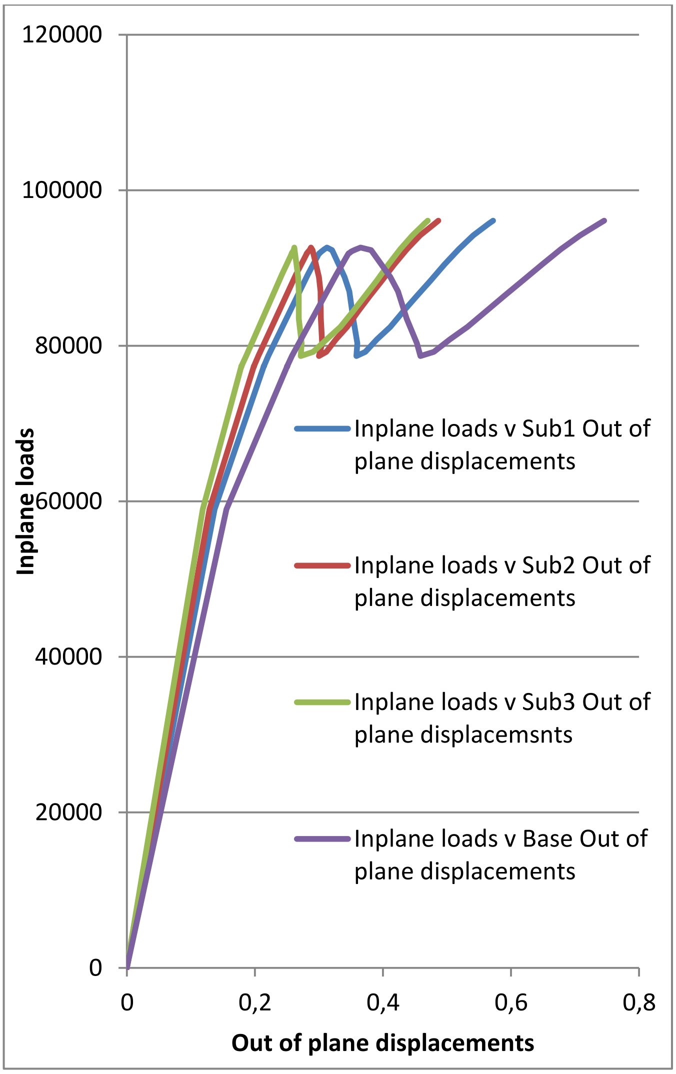

Fig -7: Inplane loads vs Out of plane displacements

In figure 7 Inplane loads versus Out of plane displacements are plotted for base and sublaminates 1, 2, 3. From this plot also it can be seen that the onset of delamination occurs at 92KN and drops to 78.5KN due to delamination growth.

3. CONCLUSIONS

In this paper a specimen considered from [8] is analyzed computationally using VCCT in ABAQUS CAE. From the analysis, it is observed that the delamination occurs at all sublaminates having initial delaminations 60mm, 44mm, 30mm at sublaminates 3, 2, 1 (Sub3, Sub2, Sub1). The loads required to cause onset and propagate delamination is 92KN which is typically a much greater value in comparison to that of a composite laminate having same geometry and delamination geometries in reverse order.

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