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RESEARCH ARTICLE OPEN ACCESS

Delamination Damage Propagation Studies of Laminated Composite Stiffened Panels

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Abstract
Delamination, a type of damage that is unique to laminated structures, it is the interlaminar separation of a composite laminate and is one of the primary failure modes of laminated composite materials. Delamination can produce asymmetric sub-laminates and final failure of the laminate is due to the resultant increase in the net section stresses and out-of-plane bending and twisting due to asymmetry. Failure of an intact stiffened panel is often associated with the separation of the stiffener from the skin, as opposed to an in-plane material failure. In the post buckling regime, failure of a composite stiffened panel is usually induced by the separation failure of a skin–stiffener interface. If the stiffened panel contains an initial defect of stringer debonding, premature failure of the structure may result if the loading conditions promote separation of stringer and skin. The torsional and rotational stiffness of the stringer plays an important role in the failure of stiffened panels The delamination between interfaces of stiffeners and skin, in between layers skin and in between stiffeners may be studied to predict the design of defect free panel. The main objective of the project to find out the strain energy release rate values which will be helpful to check the crack initiation points for the particular load in the different orientations for interface material.

I. INTRODUCTION TO COMPOSITES

Mankind has been aware **composite materials** since several hundred years before Christ and applied innovation to improve the quality of life. Although it is not clear has to how Man understood the fact that mud bricks made sturdier houses if lined with straw, he used them to make buildings that lasted. Ancient Pharaohs made their slaves use bricks with to straw to enhance the structural integrity of their buildings, some of which testify to wisdom of the dead civilization even today.Contemporary composites results from research and innovation from past few decades have progressed from glass fiber for automobile bodies to particulate composites for aerospace and a range other applications. Ironically, despite the growing familiarity with composite materials and ever-increasing range of applications, the term defines a clear definition. Loose terms like “materials composed of two or more distinctly identifiable constituents” are used to describe natural composites like timber, organic materials, like tissue surrounding the skeletal system, soil aggregates, minerals and rock.

II. CLASSIFICATION OF COMPOSITES

Composite materials are commonly classified at following two distinct levels:

- The first level of classification is usually made with respect to the matrix constituent. The major composite classes include Organic Matrix Composites (OMCs), Metal Matrix Composites (MMCs) and Ceramic Matrix Composites (CMCs). The term organic matrix composite is generally assumed to include two classes of composites, namely Polymer Matrix Composites (PMCs) and carbon matrix composites commonly referred to as carbon-carbon composites.
- The second level of classification refers to the reinforcement form - fibre reinforced composites, laminar composites and particulate composites. Fibre reinforced composites can be further divided into those containing discontinuous or continuous fibres.
- Fibre Reinforced Composites are composed of fibres embedded in matrix material. Such a composite is considered to be a discontinuous fibre or short fibre composite if its properties vary with fibre length. On the other hand, when the length of the fibre is such that any further increase in length does not further increase, the elastic modulus of the composite, the composite

is considered to be continuous fibre reinforced. Fibres are small in diameter and when pushed axially, they bend easily although they have very good tensile properties. These fibres must be supported to keep individual fibres from bending and buckling.

- Laminar Composites are composed of layers of materials held together by matrix. Sandwich structures fall under this category.
- Particulate Composites are composed of particles distributed or embedded in a matrix body. The b particles may be flakes or in powder form. Concrete and wood particle boards are examples of this category.

III. INTRODUCTION TO FRACTURE

Structural design concepts traditionally use a strength-of-material approach for designing a component. This approach does not anticipate the elevated stress levels due to the existence of cracks. The presence of such stresses can lead to catastrophic failure of the structure. Fracture mechanics accounts for the cracks or flaws in a structure. The fracture mechanics approach to the design of structures includes flaw size as one important variable, and fracture toughness replaces strength of material as a relevant material parameter.Fracture analysis is typically carried out either using the energy criterion or the stress-intensity-factor criterion. When the energy criterion is used, the energy required for a unit extension of the crack (the energy-release rate) characterizes the fracture toughness. When the stress-intensity-factor criterion is used, the critical value of the amplitude of the stress and deformation fields characterizes the fracture toughness. Under certain circumstances, the two criteria are equivalent.

Fracture Modes
Fracture Mechanics Parameter Calculation
Crack Growth Simulation

Fracture Modes

Depending on the failure kinematics (that is, the relative movement of the two surfaces of the crack), three fracture modes are distinguishable, as shown in

- **Mode I** – Opening or tensile mode
- **Mode II** – Shearing or sliding mode
- **Mode III** – Tearing or out-of-plane mode

Fracture is generally characterized by a combination of fracture modes.

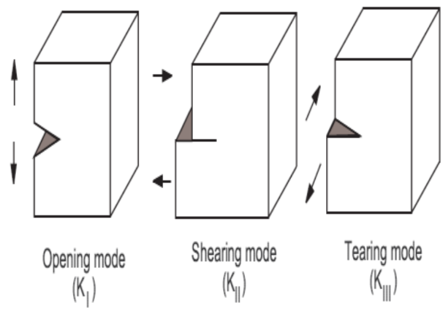


Fig.5 Schematic Fracture Modes

IV. FEA Modeling of Composite stiffened Panel:

Project Description: The assembly model consists of three parts.

- They are skin, stiffener and web.
- The element type used is solid 186. Hexahedral mesh has been used.
- The crack front has kept at distance of 126mm from one end.
- The load has applied in the different cases.
- Virtual Crack Closure technique has been used.
- Appropriate commands which supports for VCCT technique has used to extract results.

The following are the concepts related to fracture analysis:

- Introduction to Fracture
- Solving Fracture Mechanics Problems
- Numerical Evaluation of Fracture Mechanics Parameters
- Learning More About Fracture Mechanics

Software Used: ANSYS 14.5**4.2. Stiffened Panel**

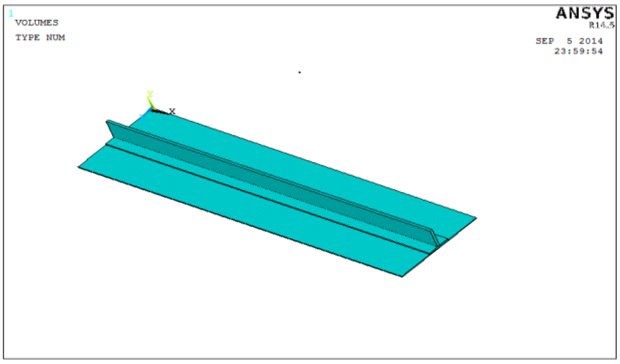


Fig. Composite stiffened panel assembly

Dimensions of the model:z
Meshed model:

- Hexahedral mesh has used.
- Element type is solid186.

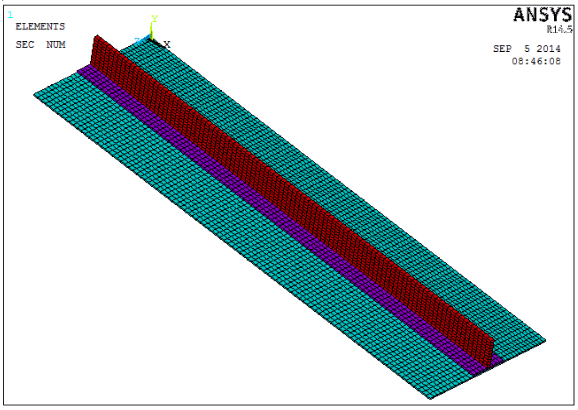
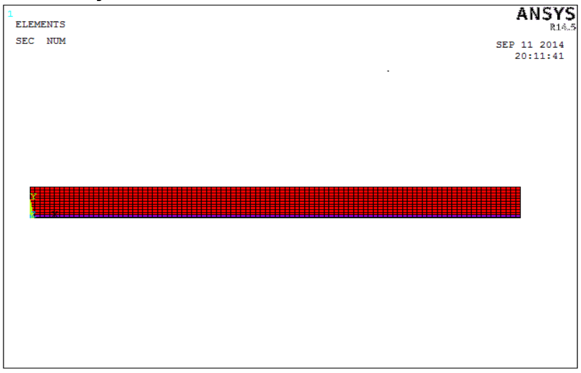


Fig.16. Meshed Model

Boundary Conditions:



Basic Boundary condition

Material Properties for E-glass Epoxy:

Linear Orthotropic Material Property	
EX	1.30E+05
EY	8000
EZ	8000
PRXY	0.3
PRYZ	0.3
PRXZ	0.3
GXY	5000
GYZ	2500
GXZ	5000

Table. Material Properties of the E-glass Epoxy

Material Orientation:
The material used is glass epoxy composite,

Material Orientation of Skin:

S NO	Thickness	Material Id	Orientation	Integration pts	Pictorial View
1	0.36	1	45	3	
2	0.36	1	-45	3	
3	0.36	1	45	3	
4	0.36	1	-45	3	
5	0.36	1	45	3	
6	0.36	1	-45	3	
7	0.125	1	0	3	
8	0.125	1	0	3	
9	0.36	1	-45	3	
10	0.36	1	45	3	
11	0.36	1	-45	3	
12	0.36	1	45	3	
13	0.36	1	-45	3	
14	0.48	1	60	3	

Table.. Material Orientation of Skin

Material Orientation of Flange:

S NO	Thickness	Material Id	Orientation	Integration pts	Pictorial View
1	0.36	2	45	3	
2	0.36	2	45	3	
3	0.125	2	0	3	
4	0.125	2	0	3	
5	0.36	2	45	3	
6	0.36	2	45	3	
7	0.125	2	0	3	
8	0.125	2	0	3	
9	0.36	2	45	3	
10	0.36	2	45	3	

Table.3. Material Orientation of Flange

Material Orientation of Web:

S NO	Thickness	Material Id	Orientation	Integration pts	Pictorial View
1	0.36	2	45	3	
2	0.125	2	0	3	
3	0.125	2	0	3	
4	0.125	2	0	3	
5	0.125	2	0	3	
6	0.36	2	45	3	
7	0.125	2	0	3	
8	0.125	2	0	3	
9	0.125	2	0	3	
10	0.125	2	0	3	
11	0.36	2	45	3	
12	0.125	2	0	3	
13	0.125	2	0	3	
14	0.125	2	0	3	
15	0.125	2	0	3	
16	0.36	2	45	3	
17	0.125	2	0	3	
18	0.125	2	0	3	
19	0.125	2	0	3	
20	0.125	2	0	3	
21	0.36	2	45	3	
22	0.125	2	0	3	
23	0.125	2	0	3	
24	0.125	2	0	3	
25	0.125	2	0	3	
26	0.36	2	45	3	

Table.4. Material Orientation of Web

Input commands for Commands used for the Analysis:

- **CINT,NEW,1**
- **CINT,TYPE,VCCT**
- **CINT,CTNC,CRACKTIP**

- **CINT,SYMM,OFF**
- **CINT,NORMAL**

Output Command for strain energy release rate

PRCINT,1

Results& Discussions:

V.Load Case Opening Load5.1.1)0 Deg Orientation of interface plate (Skin):

i)Boundary Condition:

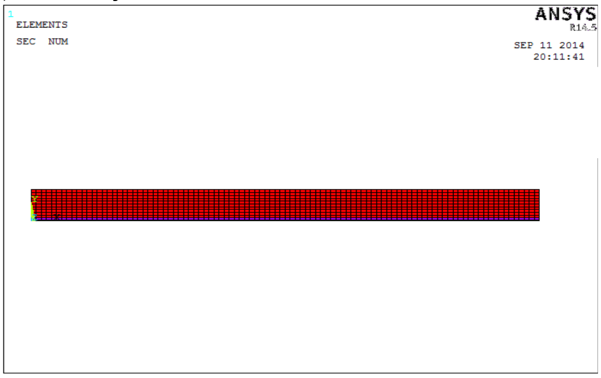


Fig.18 Opening Mode-0 Deg Orientation Boundary Condition

ii)Interface Plate Material Orientation:

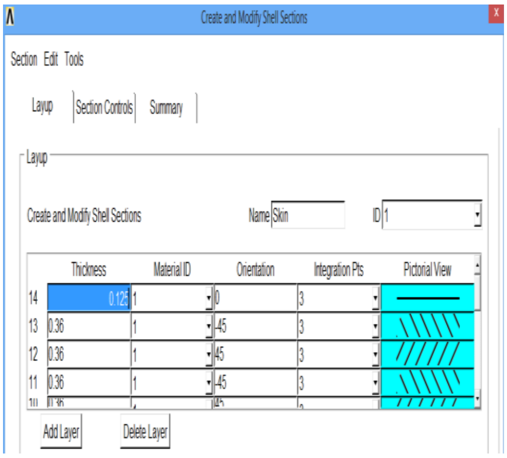


Table.5. 0 Deg Interface Plate Material Orientation

iii)Stress Plot:

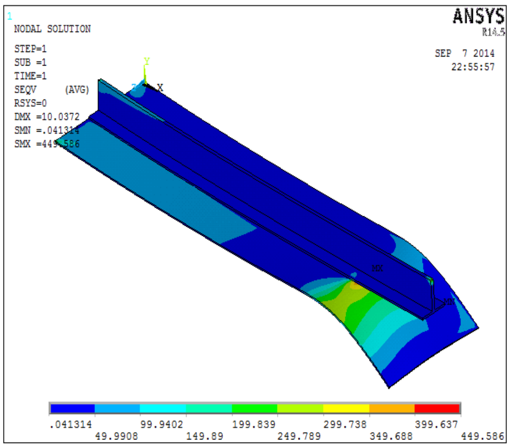


Fig.19 Stress Plot

iv)Displacement:

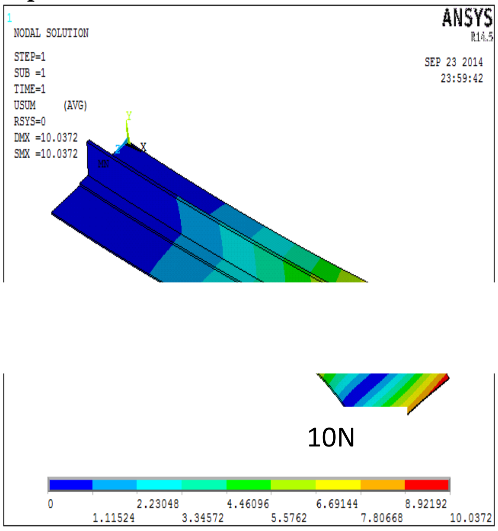


Fig.20 Displacement Plot

v) Strain Energy Release Rate Values:

S.No	Crack Front Node	G1	G2	G3	GT
1	5777	0	0	0	0
2	3008	0.59856	6.85E-02	0.10815	0.77516
3	3007	0.3915	5.17E-02	5.54E-02	0.49858
4	3006	0.33065	4.60E-02	5.25E-02	0.42917
5	3005	0.32344	4.16E-02	3.70E-02	0.40208
6	3004	0.35064	3.93E-02	3.88E-02	0.42871
7	3003	0.34821	3.86E-02	2.65E-02	0.41333
8	3002	0.39457	3.56E-02	2.95E-02	0.45965
9	3001	0.53028	3.53E-02	9.60E-03	0.57521
10	3000	0.62951	3.11E-02	1.32E-02	0.67377
11	2999	0.5333	3.50E-02	4.77E-03	0.57306
12	2998	0.40083	3.41E-02	2.03E-02	0.45528
13	2997	0.35701	[illegible]	[illegible]	.40984
14	2996	0.36214	[illegible]	[illegible]	.42517
15	2995	0.33611	[illegible]	[illegible]	.3983
16	2994	0.34404	[illegible]	[illegible]	.42336
17	2993	0.40642	4.11E-02	4.45E-02	0.49195
18	2992	0.61783	5.46E-02	9.15E-02	0.76388
19	5877	0.38257	2.74E-02	8.71E-02	0.49708

-10N

Table.6. 0Deg Strain energy Release Rate Values

vi)Graph of Strain Energy Release Rate Values:

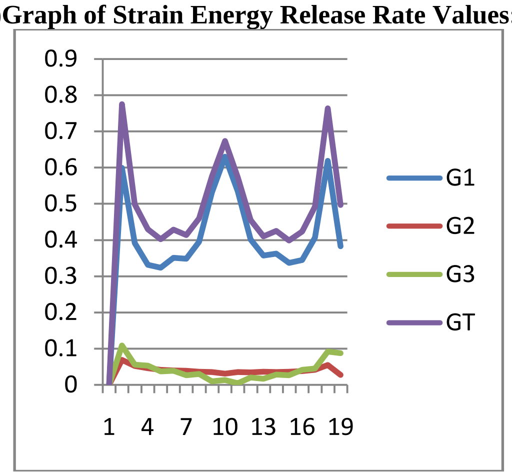


Fig.Graph of Strain Energy Release Rate Values

The highlighted points are the crack initiations for the particular load and the curve indicates the Opening Mode in which the crack initiation starts.

30 Deg Orientation of interface plate:

i)Interface Plate Material Orientation:

	Thickness	Material ID	Orientation	Integration Pts
14	0.24	1	30	3
13	0.36	1	45	3
12	0.36	1	45	3
11	0.36	1	45	3
10	0.36	1	45	3
9	0.36	1	45	3
8	0.125	1	0	3
7	0.125	1	0	3
6	0.36	1	45	3
5	0.36	1	45	3
4	0.36	1	45	3
3	0.36	1	45	3

Table..Deg Interface Plate Material Orientation

ii)Stress Plot:

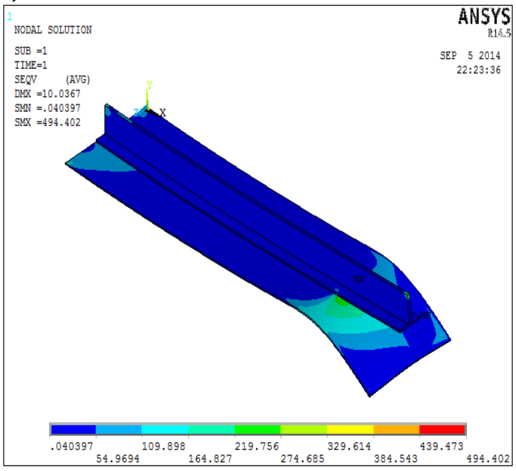


Fig.22 30 Deg Orientation Stress Plot

iii) Strain Energy Release Rate Values:

S.NO:	Crack Front Node	G1	G2	G3	GT
1	5777	0	0	0	0
2	3008	0.51777	5.21E-02	6.69E-02	0.63678
3	3007	0.3785	4.27E-02	4.09E-02	0.4621
4	3006	0.32313	3.87E-02	3.80E-02	0.39985
5	3005	0.3111	3.55E-02	2.71E-02	0.3737
6	3004	0.3345	3.38E-02	2.84E-02	0.39669
7	3003	0.33298	3.40E-02	1.83E-02	0.38538
8	3002	0.37762	3.15E-02	2.14E-02	0.43046
9	3001	0.50967	3.16E-02	5.72E-03	0.54701
10	3000	0.60492	2.74E-02	1.22E-02	0.64449
11	2999	0.51215	3.14E-02	7.23E-03	0.55076
12	2998	0.38682	3.12E-02	2.41E-02	0.44209
13	2997	0.34618	3.39E-02	2.07E-02	0.40083
14	2996	0.3525	3.40E-02	3.09E-02	0.41744
15	2995	0.33076	3.61E-02	2.91E-02	0.39594
16	2994	0.34202	3.99E-02	4.17E-02	0.42362
17	2993	0.40289	4.61E-02	4.43E-02	0.49328
18	2992	0.59	6.66E-02	8.24E-02	0.73908
19	5877	0.35825	3.52E-02	8.04E-02	0.47389

Table.. 30Deg Strain energy Release Rate Values

iv)Graph of Strain Energy Release Rate:

Fig. Graph of Strain Energy Release Rate Values

The highlighted points are the crack initiations for the particular load and the curve indicates the opening mode in which the crack initiation starts.

45Deg Orientation of interface plate:

i)Interface Plate Material Orientation:

	Thickness	Material ID	Orientation	Integration Pts
14	0.36	1	45	3
13	0.36	1	45	3
12	0.36	1	45	3
11	0.36	1	45	3
10	0.36	1	45	3
9	0.36	1	45	3
8	0.125	1	0	3
7	0.125	1	0	3
6	0.36	1	45	3
5	0.36	1	45	3
4	0.36	1	45	3
3	0.36	1	45	3

Table.. 45 Deg Interface Plate Material Orientation

ii) Von Mises Stress:

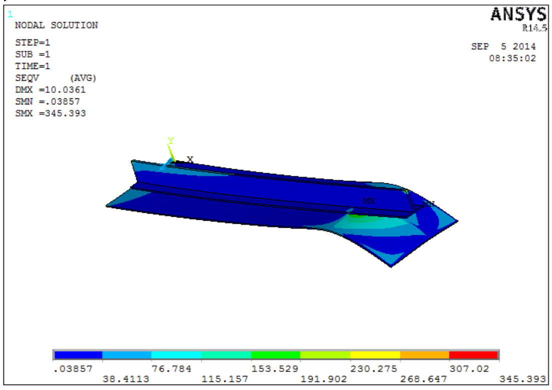


Fig.24 45 Deg Orientation Stress Plot

Stresses and Displacements Summary:

The yield strength of the material is 450 MPa.

Opening Load				
S.No	Angle of orientation(Degrees)	Stress(MPa)	Displacement(mm)	Factor of Safety
1	0	449	10.03	1
2	30	494	10.01	0.9
3	45	345	10.03	1.3
4	60	309	10.04	1.4
5	90	297	10.03	1.5

Shearing Load				
S.No	Angle of orientation(Degrees)	Stress(MPa)	Displacement	Factor of Safety
1	60	96.05	2.41	4.68
2	90	82.36	2.24	5.48

Tearing Load				
S.No	Angle of orientation(Degrees)	Stress(MPa)	Displacement	Factor of Safety
1	0	52.69	0.28	8.54
2	30	30.36	0.28	14.82
3	45	30.36	0.28	14.82

Buckling Load				
S.No	Angle of orientation(Degrees)	Stress(MPa)	Displacement	Factor of Safety
1	45	126.01	1.14	3.57
2	60	111.06	1.11	4.05
3	90	112.95	0.97	3.98

Tensile Load				
S.No	Angle of orientation(Degrees)	Stress(MPa)	Displacement	Factor of Safety
1	0	127.14	1.25	3.59
2	30	145.53	1.16	3.09
3	45	145.53	1.02	3.09
4	60	123.36	0.98	3.64

Contact Condition-Buckling Load				
S.No	Angle of orientation(Degrees)	Stress(MPa)	Displacement	Factor of Safety
1	0	127.15	0.94	3.53
2	30	145.53	0.96	3.09

Contact Condition-Shearing Load				
S.No	Angle of orientation(Degrees)	Stress(MPa)	Displacement	Factor of Safety
1	0	100.91	2.16	4.5
2	30	59.47	0.94	7.62

Table.31 Stresses and Displacements Summary

V. CONCLUSIONS

Composite materials have been used in structures for many years. Composite parts have been used extensively in aircraft structures, automobiles, sporting goods, in and many consumer products. The main objective of the project is to predict the delamination initiation and propagation in a skin stiffener joint used extensively in aerospace applications. The concept of strain energy release rate has been used to predict the location of crack initiation and propagation in composite structures. The composite stiffened panel is modeled and fracture analysis have been carried out using ANSYS software. Further, to find out the strain energy release rate values, virtual crack closure technique has been used. The variation of strain energy release rate along the delamination front provides the information of probable location of delamination propagation. Also, the mode of propagation can also be predicted from the graphs. Delamination of composite laminate skin with T-stiffener subjected to different loading conditions has been investigated. Based on the investigation the following conclusions has been drawn:

- There is a significant effect of ply orientation on the energy release rate. For ply orientation of 0^o the energy release rate is 0.62 J/m^2 and is the highest in the opening mode i.e mode-I for out of plane loading.
- For in-plane shearing load, 90^0 orientation has influence with the energy release rate of 0.023 J/m^2 which is much lesser compared to out of plane loading.
- The skin-stiffener joint subjected to buckling load predicted the possible of Delamination initiation is maximum when the ply orientation adjacent to the delaminated laminate is 60^0. It is observed that the Delamination propagation is dominated by shearing mode only.In case of tearing load, for ply orientation of 0^0 the strain energy release rate value is 0.00012 J/m^2 and is highest in shearing mode.
- For tensile loading, 60^0 orientation has major influence with the energy release rate of 0.0013 J/m^2
- For buckling load, all the orientations has very good factor safety for the external loading and 60^0 orientation has highest energy release rate and 90^0 has lowest energy release rate. Shearing mode has highest energy release rate values.
- In case of contact nonlinear condition- Shearing load, for the ply orientation of 30^0 the energy release rate is 0.023 J/m^2 and is highest in tearing mode. And also in case of buckling load, for the orientation of 30^0 the energy release rate is 0.00042 J/m^2.

Future Scope: The Crack propagation study with the same model(composite stiffened panel) would yield bettered results. The number of iterations can be done by using other stiffeners for example I Stiffener.

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