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Multi Disciplinary Delamination Studies In Frp Composites Using 3d Finite Element Analysis

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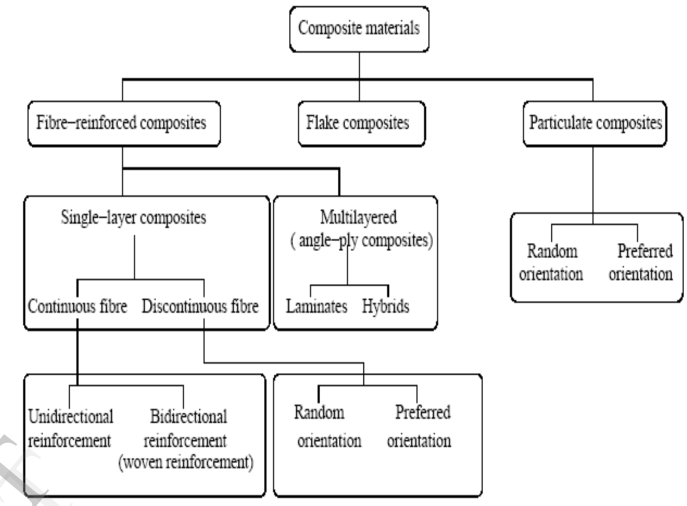
Abstract: FRP laminated composites have been extensively used in Aerospace and allied industries due to their inherent advantages over conventional materials. However these are also susceptible to damages especially under transverse loading. Failure modes of such laminated structures are different than those of conventional metallic materials. One important and unique mode of failure in such components is Delamination. Delamination is separation of adjacent plies/laminae due to existence of interlaminar stresses. This mainly occurs at free edges or around discontinuities depending upon the stacking sequence of the laminate. Once Delamination occurs, it becomes important to know whether the laminate could still be used with the existing delamination or up to what size of the Delamination the laminate could be used. So the present work aims at analyzing a laminate having Delamination to determine the severity of the existing Delamination and the propensity of the Delamination growth. 3DFE analysis along with concept of LEFM will be used the FRP laminated composites (1)

A Composite material is a material brought about by combining materials differing in composition or form on a macro scale for the purpose of obtaining specific characteristics and properties.

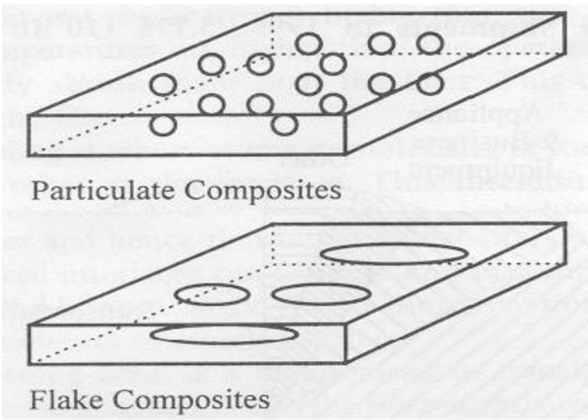
CLASSIFICATION OF COMPOSITE MATERIALS BASED ON REINFORCEMENT



HYBRID COMPOSITES

Particulate composites consist of particles, whose dimensions are approximately equal in all directions immersed in matrices such as alloys and ceramics

Flake composites consist of flat reinforcement of matrices. They have high theoretical modulus and low cost compared with fibrous composites



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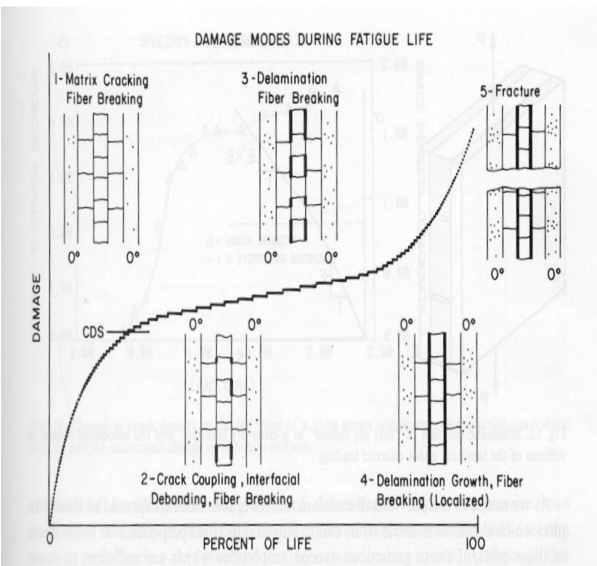
DEFECTS IN FRP COMPOSITES

Defects or flaws in composite materials can be divided into two categories viz. process induced and service related. The first type of defects is mainly created at the time of molding the laminate and depends on the particular process used for manufacturing the composite part. The process-induced defects commonly encountered in polymer matrix composites are as follows. Broken fibers due to scratches or cuts, contamination due to foreign particles, voids which are formed by entrapped air between the prepreg layers, missing plies, ply gap and ply overlap, non uniform laminate thickness, resin-rich or fibre-starved areas, fiber misalignment, under cure or variation in the degree of cure and fibre waviness or kinking. The fibre waviness can be due to improper tensioning during prepreg preparation, filament winding and pultrusion. The service-related defects are caused by unintentional overloading, low energy impacts, fatigue and environmental factors.

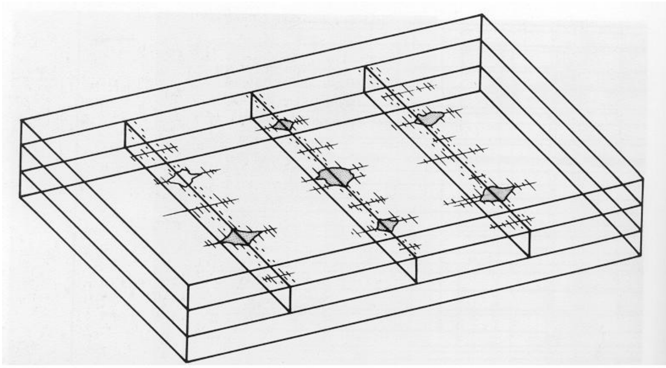
MODES OF FAILURE



A schematics picture of damage development in fibrous composites.

DELAMINATION

The delamination is caused by a mixed mode growth of interlaminar cracks, which is driven by the strong interlaminar stresses.(2)

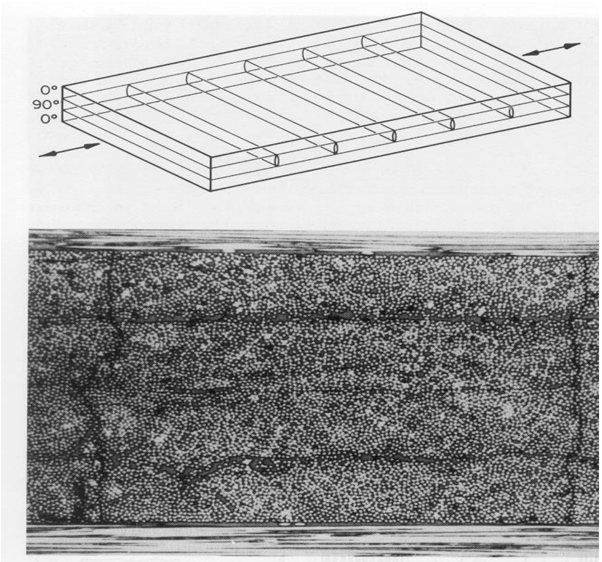


DELAMINATION IN FRP COMPOSITES

Delamination or interlaminar debonding occurs in laminate when it is subjected to loading because of engineering property mismatch between successive layers.

Delamination may also occur due to number of reasons such as

- Fibre breakage
- Matrix cracking
- Especially due to low velocity impact,



The fig illustrates the matrix crack in FRP composite.

FRACTURE MECHANICS APPROACH

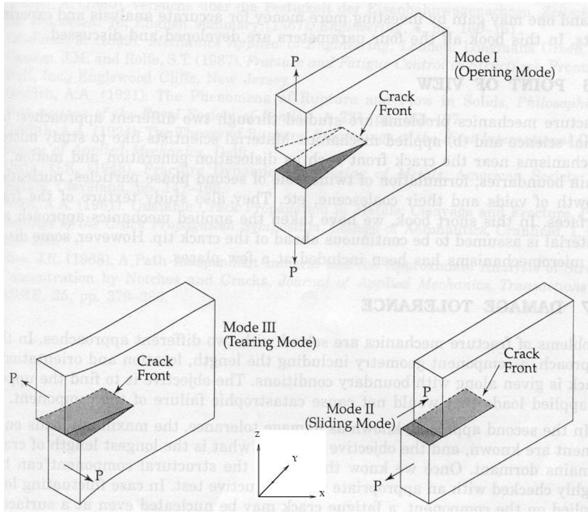
Two important parameters mostly used for assessing the severity of an existing crack are Stress Intensity Factor and Strain Energy Release Rate.

Stress Intensity Factor, K elegantly characterizes a crack and relates two independent variables.

- The far field stress
- The Crack length (a)

The Strain Energy Release Rate, G is defined as the energy release per unit increase in crack area during crack growth

HREE MODES OF FAILURE



FATIGUE LOADING OF FRP COMPOSITES

Fatigue is a form of failure that occurs in the structures subjected to dynamic and fluctuating stresses.

The fatigue failure is catastrophic in nature, occurring suddenly and without warning. Fatigue loads are of two types

Low cycle fatigue

High cycle fatigue

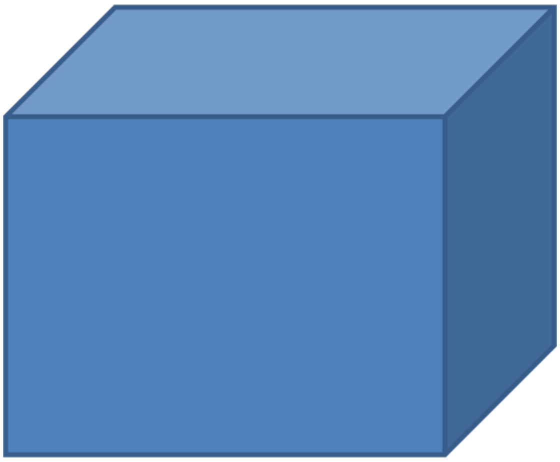
LOW CYCLE FATIGUE:- The magnitude of fluctuating load is no longer in the elastic range of the material, the body especially in highly localized areas at stress concentration region and number cycles for failure is expected to be relatively low such fatigue failure is termed as “low cycle fatigue”.

HIGH CYCLE FATIGUE: - The deformations are totally elastic and then have longer fatigue life. Such fatigue is called “high cycle fatigue”.

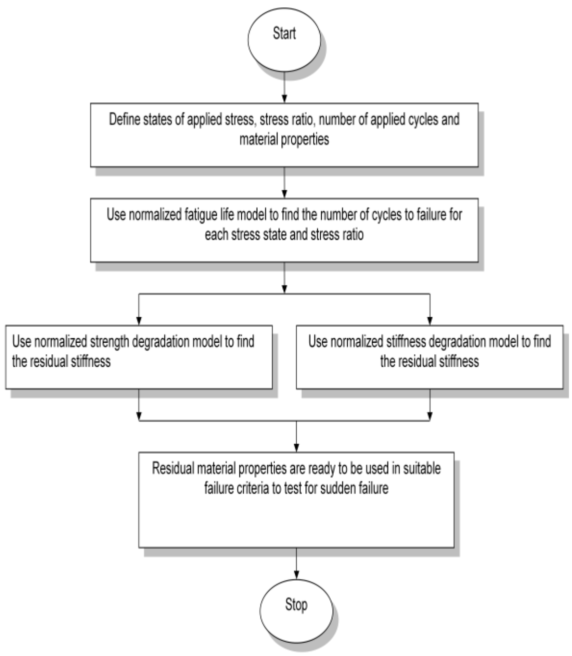
- **FE Analysis of FRP Composites**

➢ Solid 46 is a layered 8-node element of ANSYS designed to model laminated composites.

- The element allows up to 250 different material layers.
- If more than 250 layers are required, a user-input constitutive matrix option is available.
- The element has three degrees of freedom at each node: translation in the *x; y; z* directions.

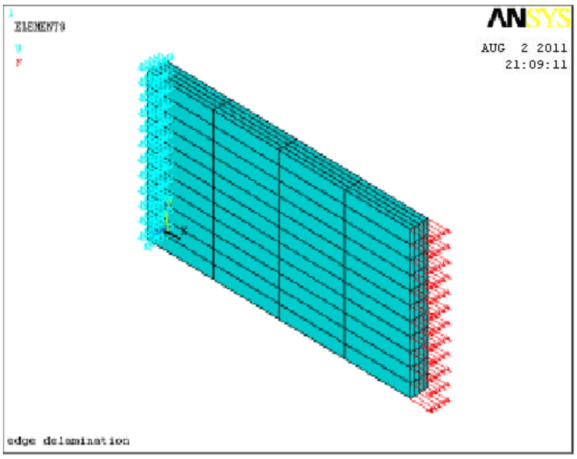


Flow chart of generalized material property degradation technique at the ply level



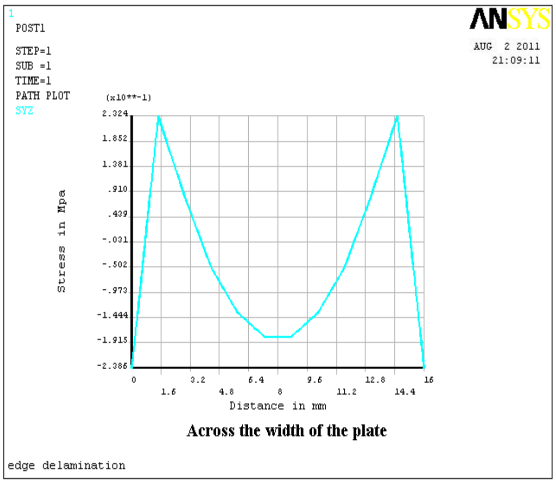
RESULTS AND DISCUSSIONS

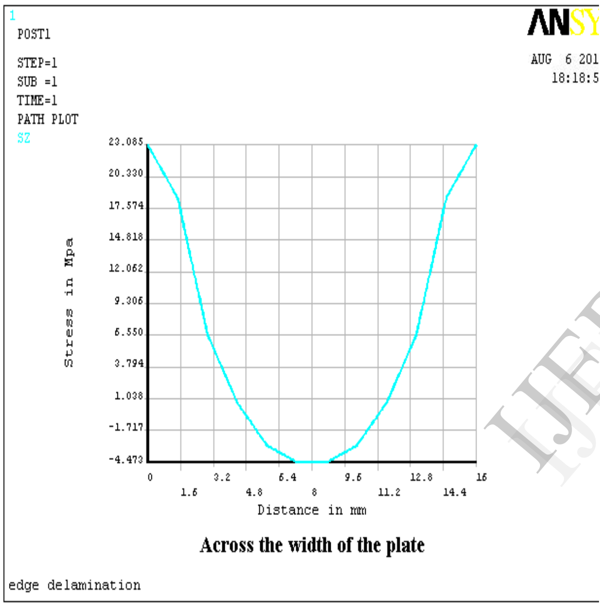
- A Plate made of glass/epoxy having a stacking sequence(0/45) has been considered. for these plate interlaminar stresses along the width of the plate have been considered
- In order to fix the interlaminar stresses responsible for delamination a full 3D FEA has been performed.

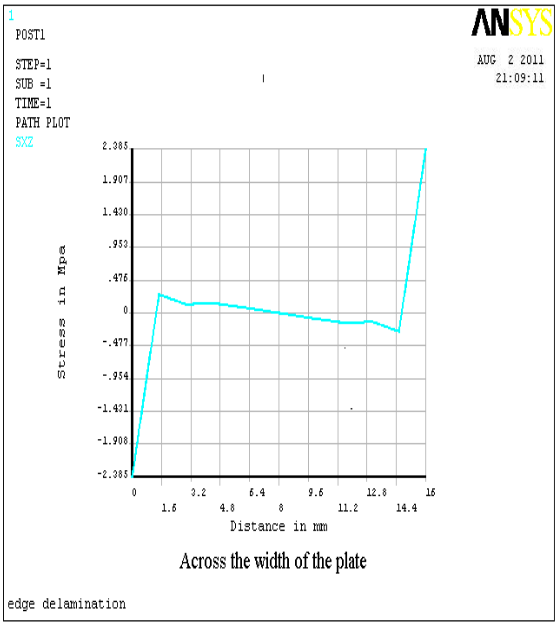


- Interlaminar stresses ,and are responsible for delamination growth. For the above FE model the distributions of interlaminar stresses across the width of the plate.
- From these results, we can observe that the stress is very high at the edges of the considered plate as compared to mode-II andmode-III,causes mode-I (opening mode) delamination.
- Mode-I delamination growth is more predominant as compared to other two modes.

Mode I&II&III: Variation of interlaminar shear stress (σzz) across width of the plate



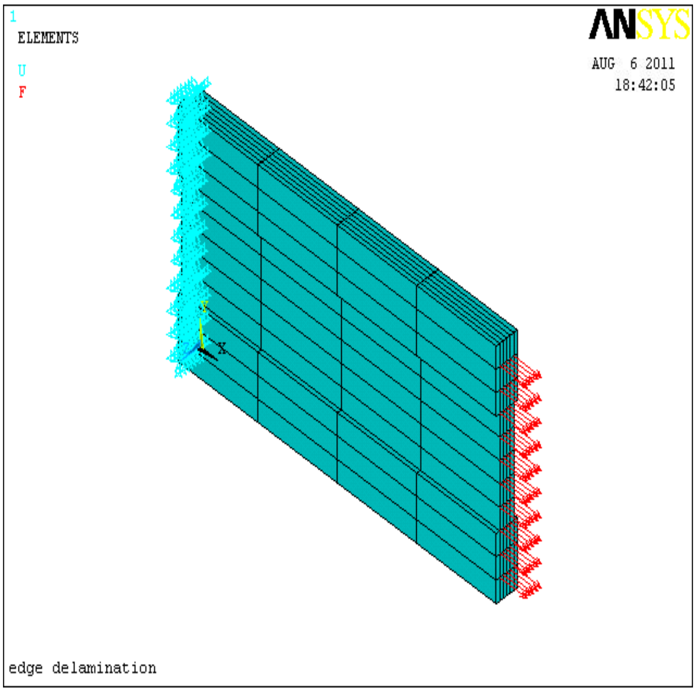




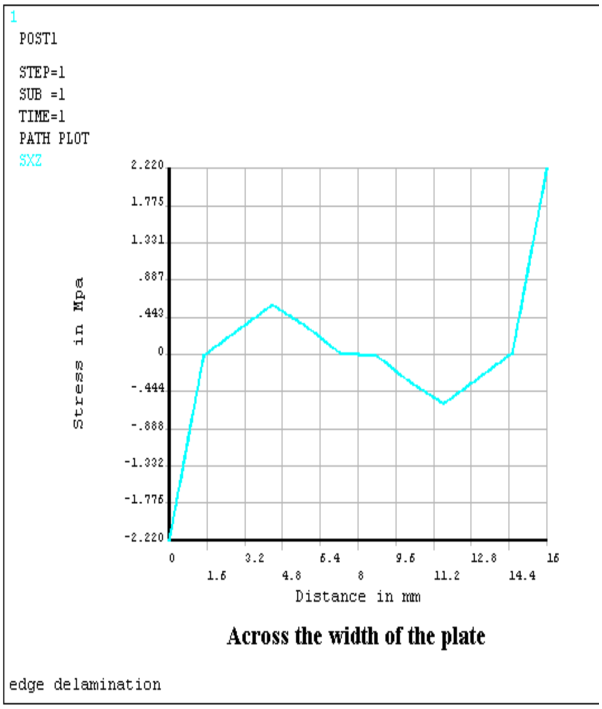
FROM MODES I & II & III

- Observe that the stress is very high at the edges of the considered plate as compared to and. Causes mode-I(opening mode) delamination. (3)
- The mode-I delamination growth is more predominant as compared to other two modes of delaminations viz., mode-II, mode-III.
- For reducing the intensity of interlaminar stresses at the edges of the plate, two cups of one-fourth size of width of the plate at the edges perpendicular to width direction have been considered.
- By considering two cups of stacking sequence at the edges, the intensity of interlaminar stresses have been reduced as compared to the interlaminar stresses due to the axial loading without cups on the plate.

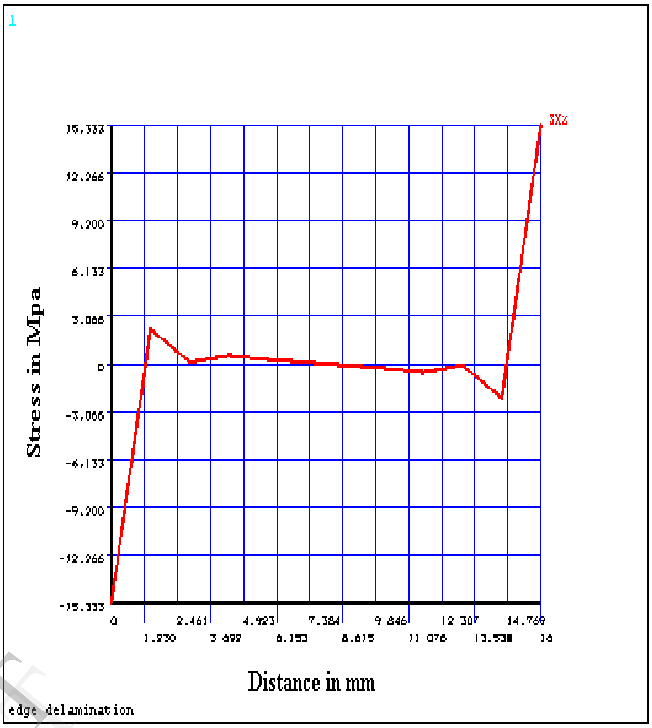
3D FE mesh of the laminate with cups at the edges width of the specimen



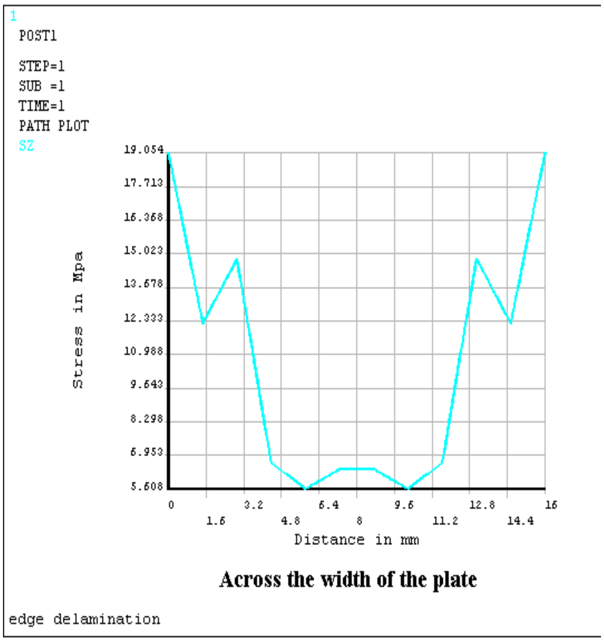
Variation of interlaminar shear stress (σXZ) across width of the plate with cups



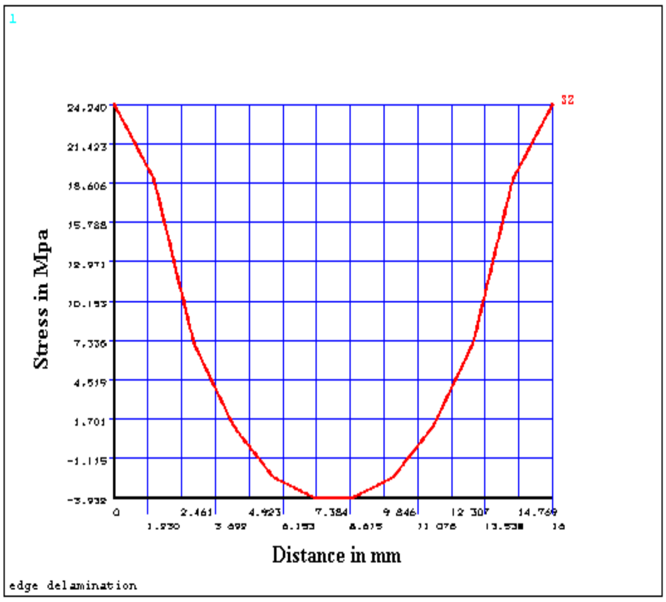
Varition of interlaminar shear stress (σzz) across width of the plate without cups for the ratioEx/Ey=15



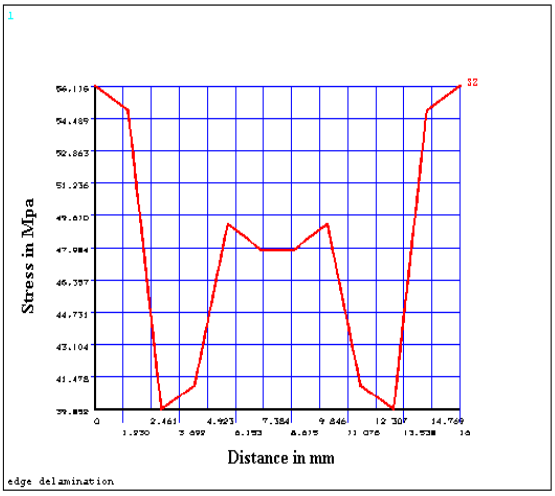
Variation of interlaminar shear stress (σZZ) across width of the plate with cups at the edge

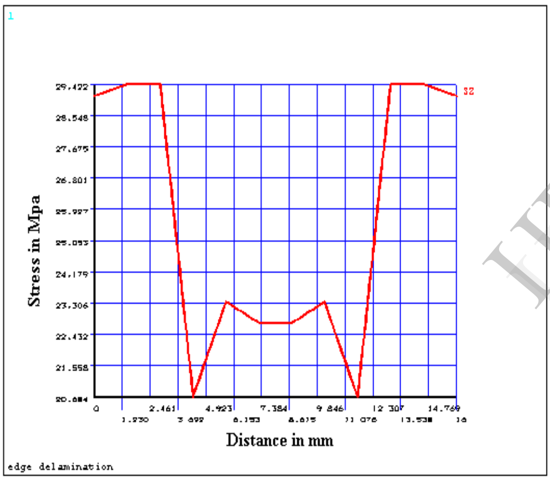


Variation of interlaminar shear stress (σzz) across width of the plate without cups for the ratio Gxy/Gyz =5



Variation of interlaminar shear stress (σzz) across width of the plate with cups for the ratio Gx/Gy=10 and15





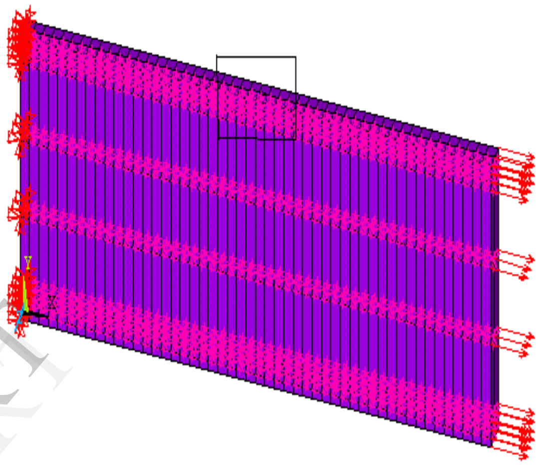
- With and without cups the change in the intensity of maximum loading for fatigue analysis.

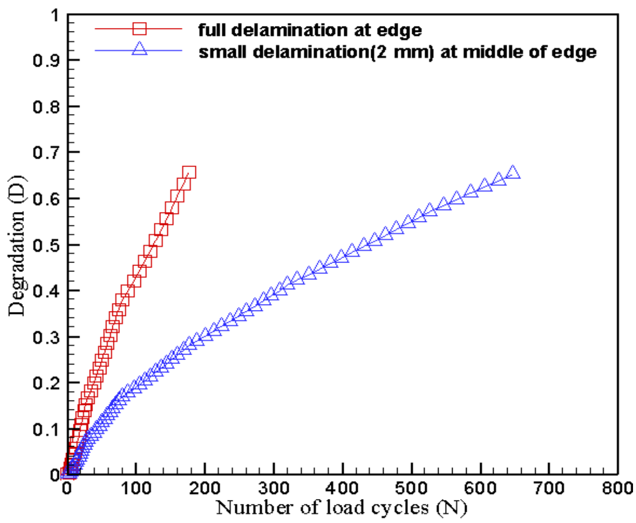
- As a result of fatigue analysis, the fatigue life of the component as well as degradation behaviour of the value of interlaminar stresses is negligible in axial loading by increasing the ratio of shear moduli.

- Now for this model, static load of 10 N is applied axially in x-direction. Then using ANSYS the problem is solved. Then the maximum stress due to loading is considered and it is taken as the amplitude of cyclic

- plate due to stiffness reduction has been obtained.

3D FE mesh of the laminate specimen with small edge delamaination of size 2 mm





- Comparison for variation of stiffness degradation with no of cycles for (0/45)laminate having small edge delamination(2mm) and full edge delamination at the edge of the plate.
- The component is assumed to be failed, if its strength is reduced to 65% of

the static strength [13] for continuous fibers of laminate

- The laminate has failed after 177 load cycles for full delamination, and in the case of small delamination it is 647 load cycles. I.e. plate having full delamination of edge will fail earlier than that of small delamination. In case of full edge delamination, delamination growth rate is also high.

CONCLUSIONS

With an objective of performing delamination of FRP composite laminates under fatigue loading the following work has been done in the first phase of the work:

I. Modeling of edge delamination and analysis using 3D Finite Element Analysis is performed under static loading.

II. Developing the methodology of fatigue analysis of delamination in FRP composite laminate using 3D FEA. From these the following important conclusions have been drawn.

1. In case of axial loading, Interlaminar stresses , and are responsible for delamination growth .The stress is very high at the edges of the considered plate as compared to and .

2. In case of axial loading, the interlaminar stress distributions of FRP composite laminates are high at the edges due to shear stress variation or due to mismatching of material properties.

3. In the case of axial loading, FRP laminated composites having delamination at edges, the mode-II and mode-III are negligible for i.e. mode-I delamination is more predominant.

4. Intensity of inter laminar stresses have been reduced as compared to the inter laminar stresses due to axial loading without cups on the plate.

5. The value of is decreased from 23.085 Mpa (tensile) to 19.054 Mpa (tensile) .By using cups at the edges, the severity of mode-I failure has been reduced

6. Intensity of inter laminar stresses have been increased in case of axial loading, by increasing the ratio of young’s moduli(Ex/Ey)

7. Change in the Intensity of inter laminar stresses have been negligible in case of axial loading, by increasing the ratio of shear moduli(Gxy/Gyz)

8. SERR depends on length of delamination considered, for small length of delamination the strain energy release rate is very low and it will take more number of cycles than the full delamination case.

9. Knowing the degradation behaviour, static strength distribution and the global stiffness reduction of the composite laminate, the present model can be used to predict the fatigue life for different applied cyclic stresses.

SCOPE OF FUTURE WORK

1. The model should be extended for fatigue damage of composites subjected to multi-axial stresses rather than uni-axial loading.

2. Multiple delaminations at other interfaces could be considered.

3. Delamination as well as matrix cracking could be considered.

4. Dynamic delamination propagation could be incorporated in the FE model.

5. Effect of impact loading could be studied.

6. The cumulative fatigue damage of composite laminates subjected to variable cyclic loading with different sequence, needs to be addressed for many engineering applications.

7. The stress redistribution factor at different applied stress levels associated with different damage modes, such as matrix cracking, debonding and local delamination should be re-examined, so that the residual strength and fatigue life of composite laminates can be evaluated in agreement with the damage events which actually occur in the composite.

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