Damage Tolerance Of Composite Laminate subjected to Edge Impact

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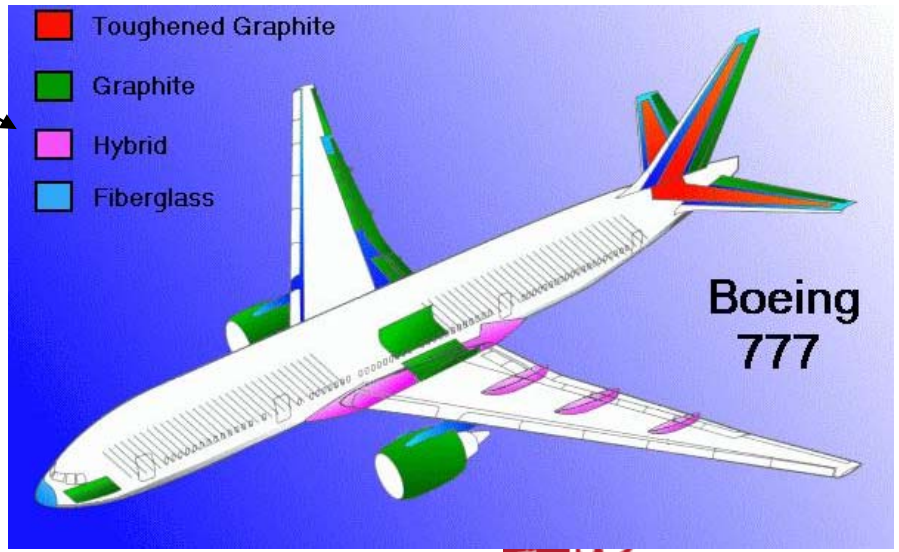
Introduction - Why On-Edge Impact ?

- Few studies on Damage Tolerance of edge impact to composite laminates.
- Becoming increasingly important as laminates are introduced in commercial aircraft
- Low velocity impacts can arise in maintenance around inspection hatches
  -Tools
  - Equipment



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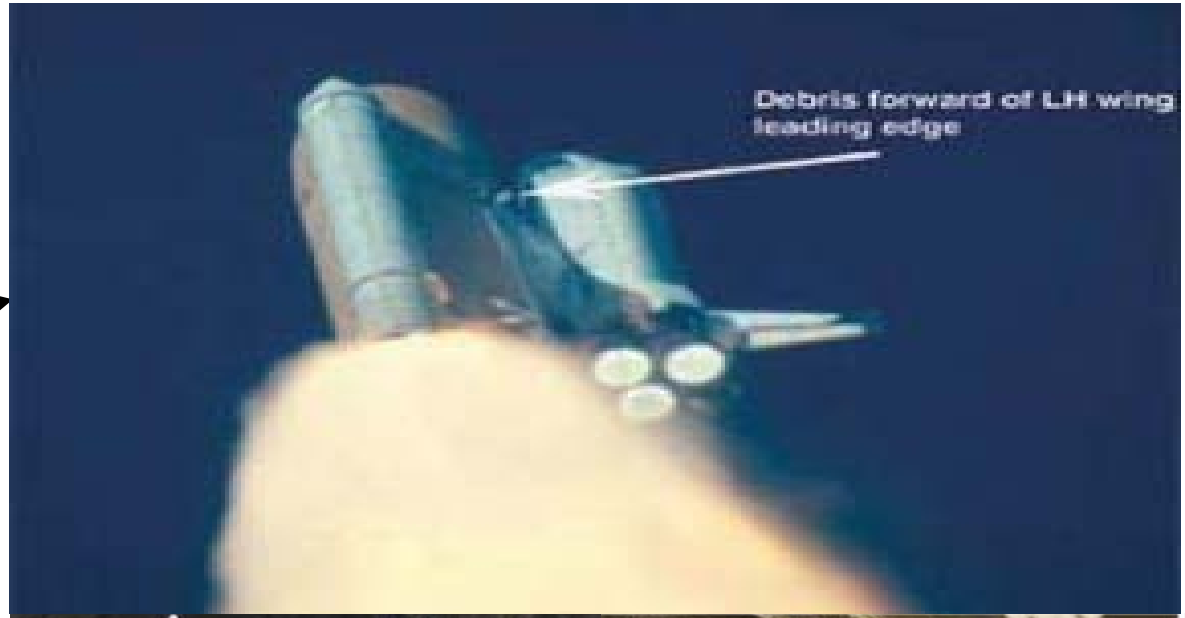
Example of Edge Impact-Columbia Disaster

Figure shows debris struck the Leading Edge of the left wing, damaging the Shuttle's Thermal Protection System during Shuttle launch.



Research by Columbia Accident Investigation Board showed that an initial foam impact test on a section of an reinforced carbon-carbon left-wing leading edge showed visible and significant impact damage on RCC panel.

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Presentation Outline

- Materials
- Part I - Edge Impact
  - Low Energy Levels:
    1J 2J 3J 4J 5J
  - Constant impactor mass: 0.740 Kg
    -Variable height/velocity
  - Tested near-edge and on-edge
    -Laminate thickness 2 mm and 4 mm
  - Finite Element Analysis
- Part II – Compression After Edge Impact
  - Crosshead Speed used in Experiment : 0.5 mm/min
  - Load Cell Range : Range from 0 to 150 kN (Max.)
  - Laminate thickness 2 mm and 4 mm
  - Results:
    - CAI - Near- edge results
    - CAI - On- edge results
    - CAI - Comparison of results
- Conclusions

Materials

Glass Fibre/Epoxy laminates

- **Epoxy Resin= *Hunstman LY564***
- **Glass Fibre = Cotech EQX 1034 Style 3200, quasi-isotropic (non-stitched) lay-up**

↓

***Manufacturing Technique :* Vacuum Assisted Resin Transfer Moulding (VARTM)**

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Laminate Thickness & Lay-Up

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- **Thickness :**
- **Ply thickness = 0.25 mm**
- **Laminate Thickness: 2mm**
- **Lay-Up: $[0/+45/90/-45]_s$**

- **Thickness :**
- **Ply thickness = 0.25 mm**
- **Laminate Thickness: 4mm**
- **Lay-Up: $[0/+45/90/-45]_{2s}$**

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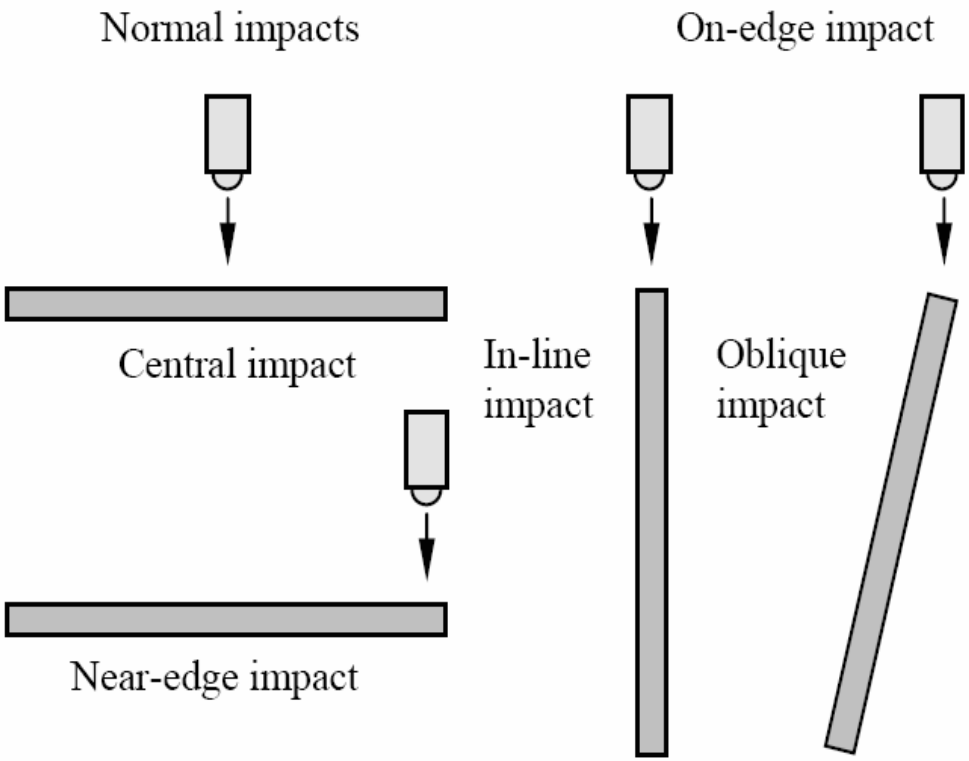
Part I - Edge Impact
Edge Impact Conditions

Current work:

Near-edge and On-edge impact on GFRP laminates

Future work:

Later we intend to consider oblique Edge impact



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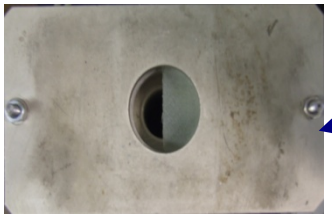
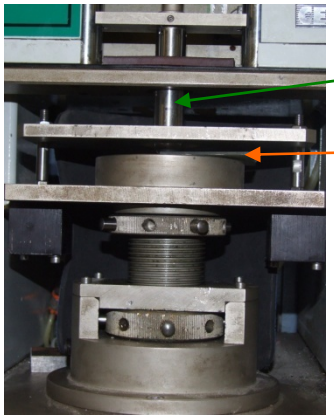
Design Of Edge Impact Tests

Same constraints applied arrangement used for near edge and on edge tests

Near Edge



Top View

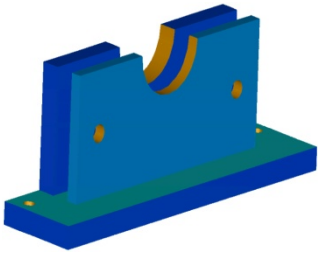


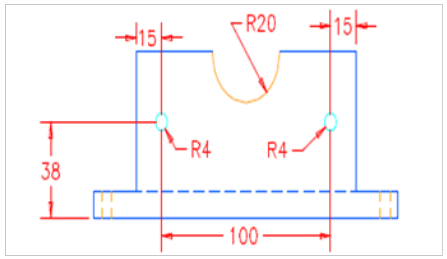
Impactor

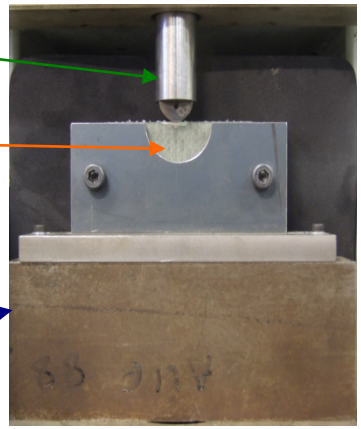
Laminate

Side View

On Edge







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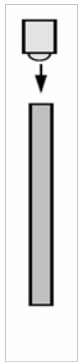
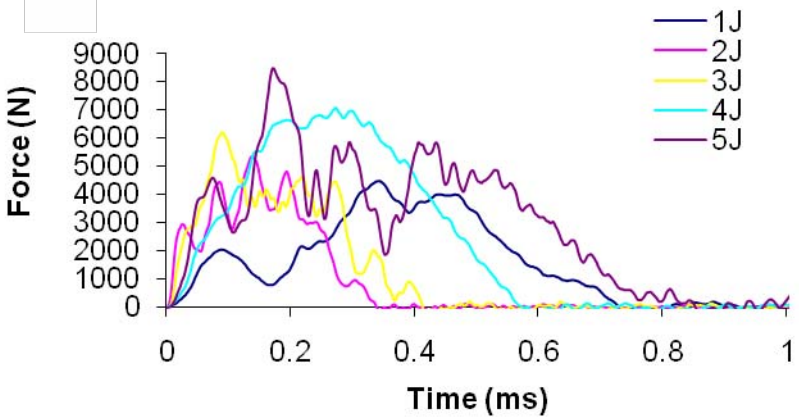
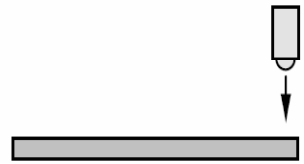
Edge Impact-Results
Force Vs Time – Thin Laminate (2mm)

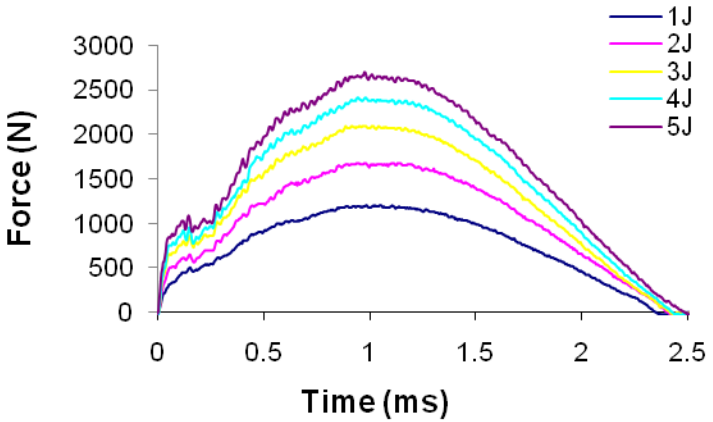


On Edge



Near Edge





- Impact Force for On Edge Impact is much higher compared to Near Edge impact.
- Impact event time reduced for On Edge Impact.
- On edge Impact shows high oscillation and frequency curves while near edge impact shows smooth curves.

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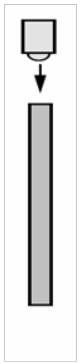
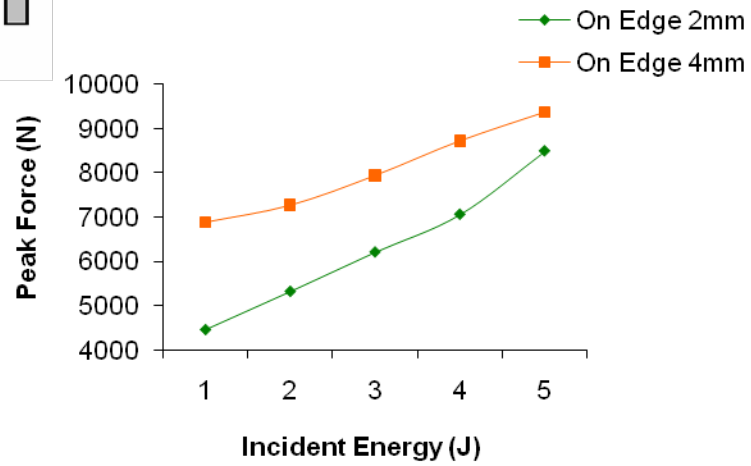
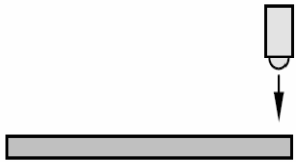
Edge Impact-Results
Peak Force Vs Incident Energy

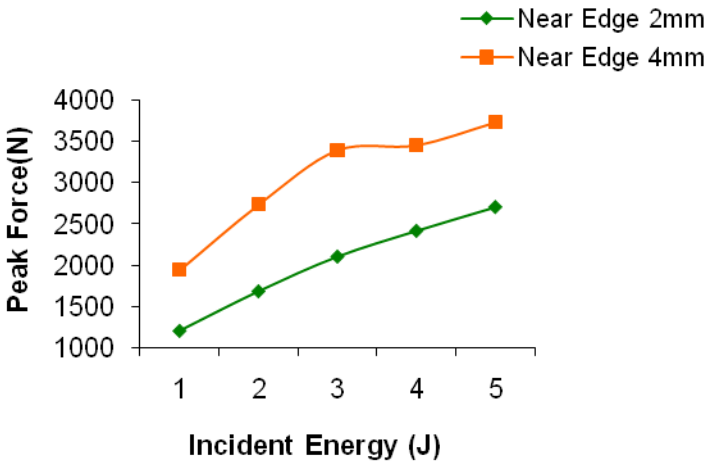


On Edge



Near Edge





- Peak force almost doubled for thicker laminate.
- Increase in peak force with incident energy appears higher at lower incident energy.

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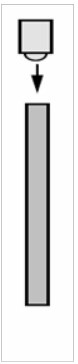
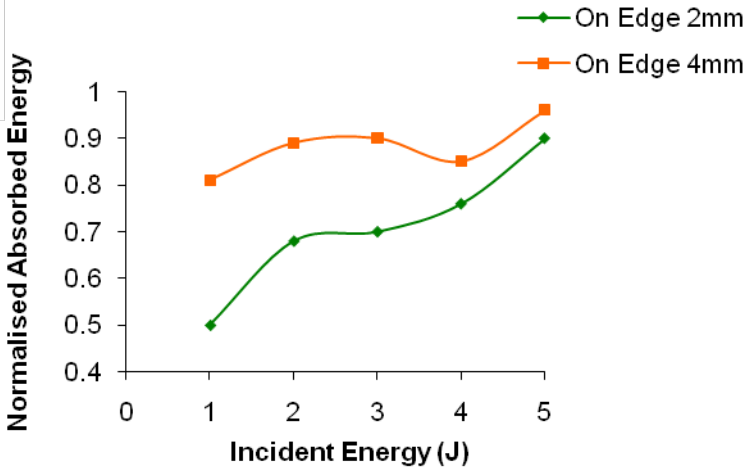
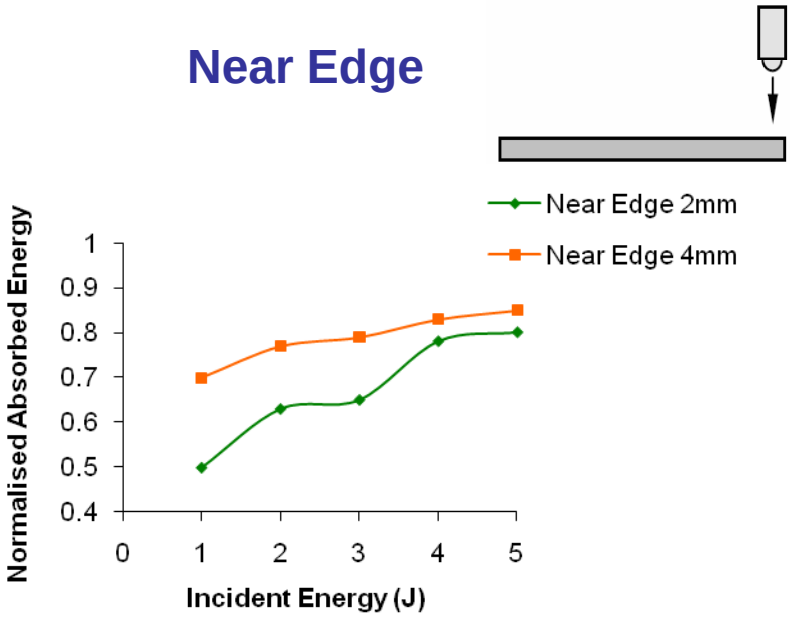
Edge Impact-Results
Normalized Absorbed Energy Vs Incident Energy



On Edge



Near Edge



- More energy absorbed for thicker laminate.
- More energy absorbed for On Edge Impact.
- More energy absorbed for higher incident energy.
- Less effect of thickness for higher incident energy.

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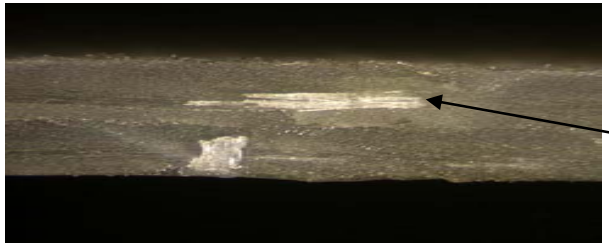
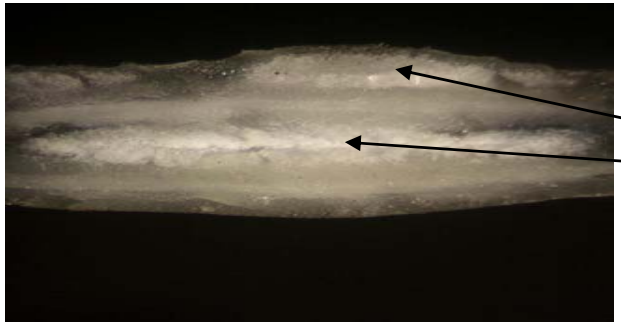
Damage Area : Edge View



Near edge 2 mm; 2J

Single Delamination



On edge 2 mm; 2J

Multiple Delaminations

- Damage for On Edge impact appears to induce more fibre failure.
- Delaminations for Near Edge impact extends further into the laminate.

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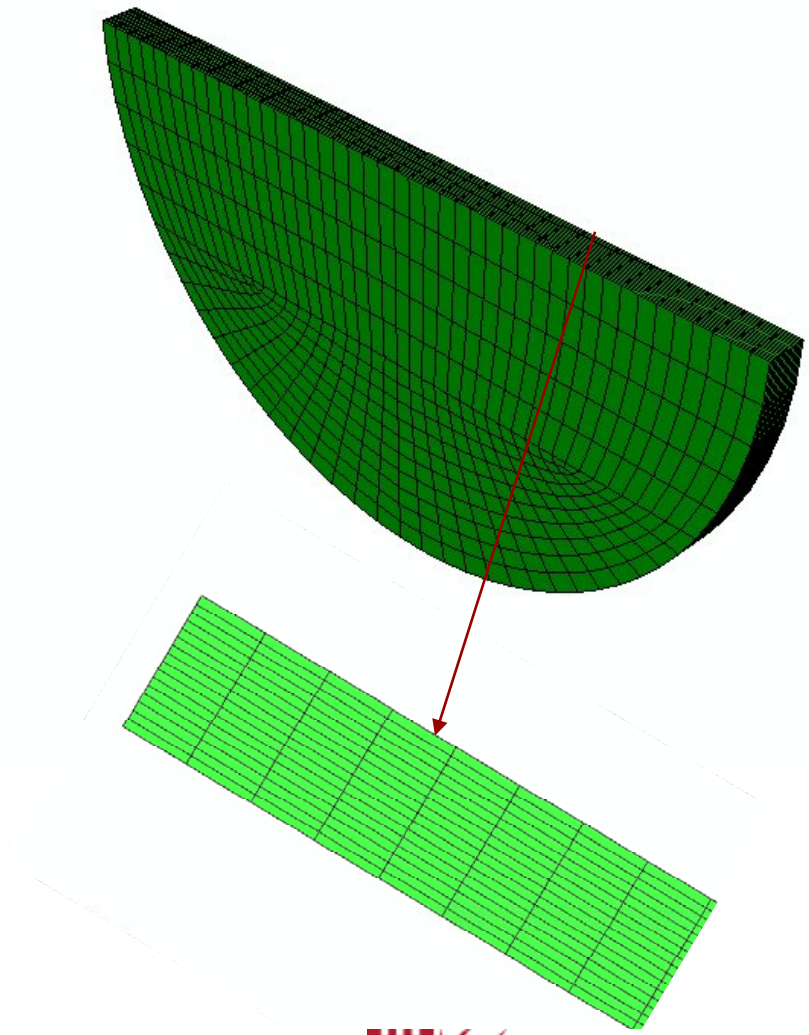
The Finite Element Model

- Abaqus/Explicit
- Element type: C3D8R
  8 Noded Linear Brick
  - Reduced integration
  - Hourglass control
- Plate is modelled at ply level
  - 2 layers of elements per ply
  - 24,000 elements for 2mm plate
- Failure not included in these simulations
  - Will be added in future simulations



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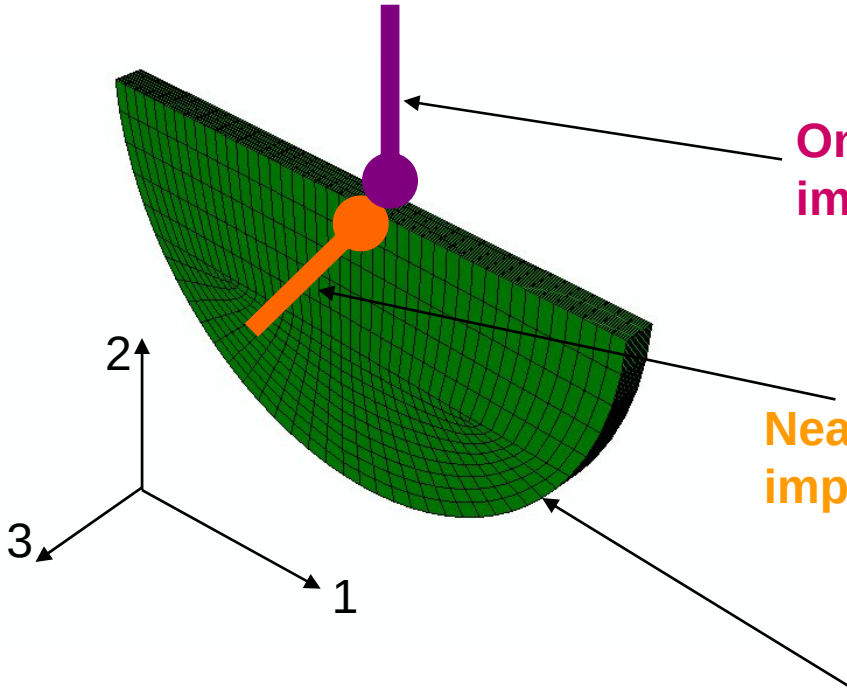
Boundary Conditions



On edge impact:
impactor free in 2

Near edge impact:
impactor free in 3

Outer curved edge of plate fully constrained

- All simulations for 3J impact using experimental values of impactor mass and velocity.
- Simulations are carried out for thin laminate 2mm

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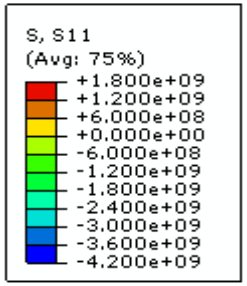
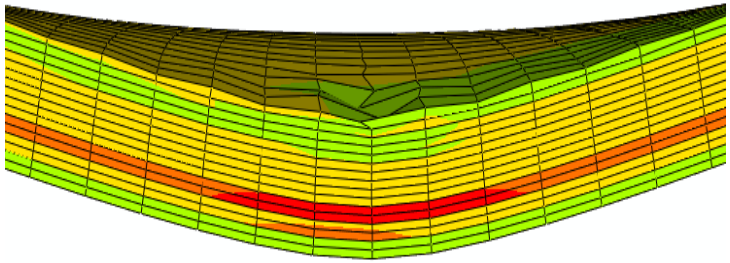
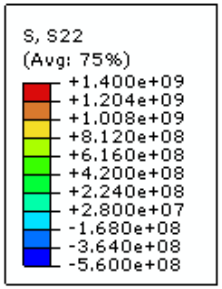
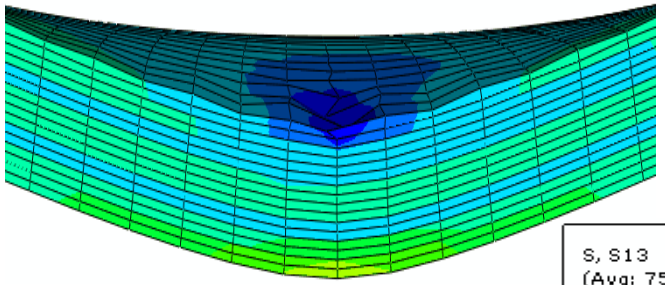
Finite Element Results: Stress Analysis: Near Edge



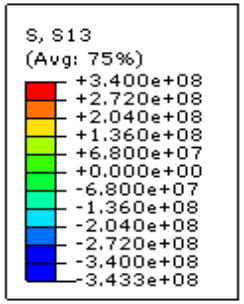


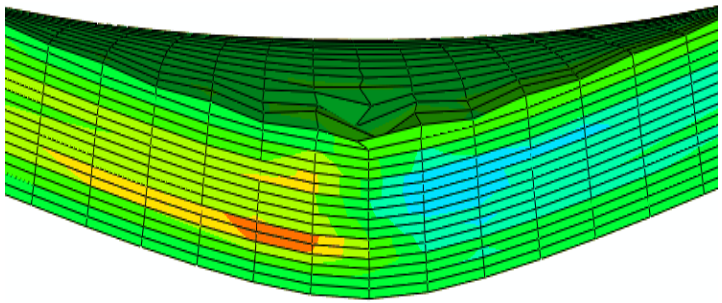
Fibre direction stress





Transverse fibre stress





In-plane shear stress

Maximum stresses around 45^0 plies where delaminations were observed.

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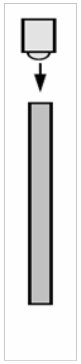
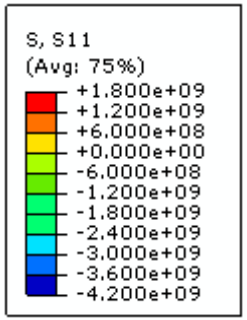
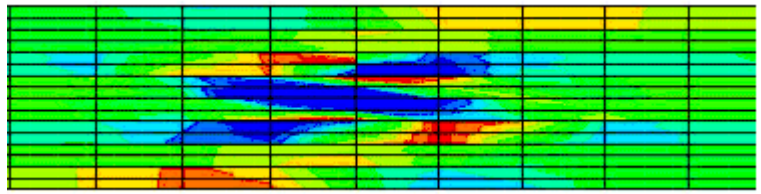
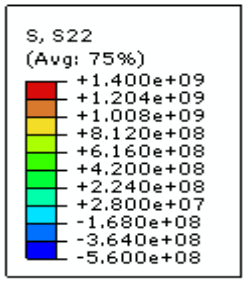
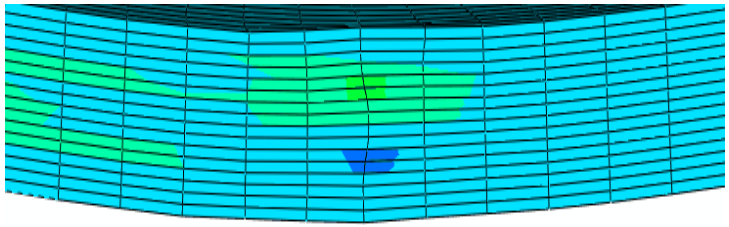


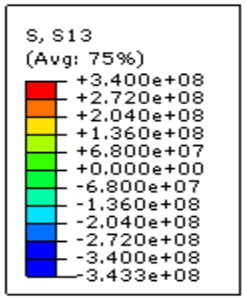
Finite Element Results: Stress Analysis: On Edge

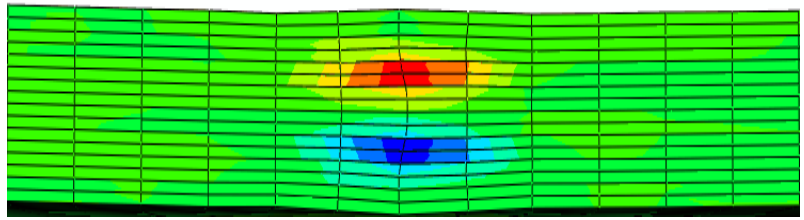












Maximum stresses are more distributed through the whole thickness.

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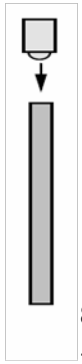
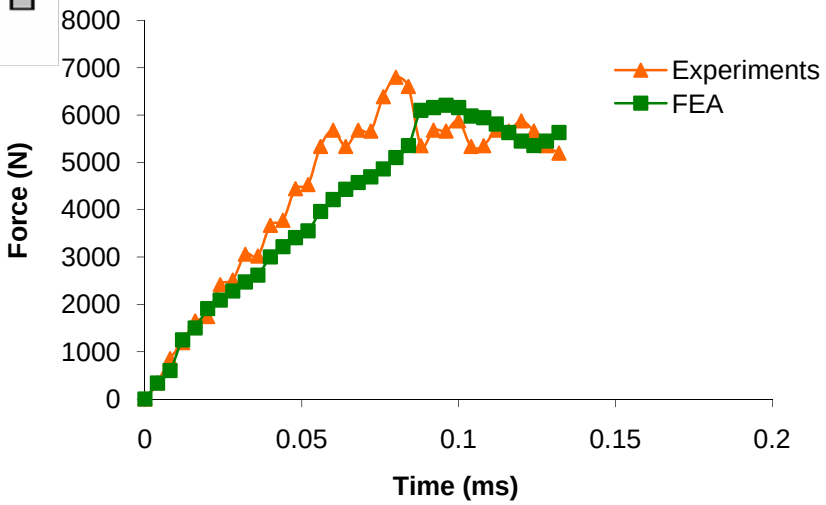
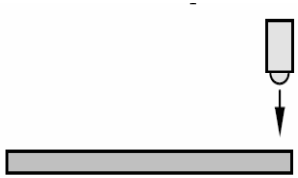
Comparison of Experiments & FEA
Force Vs Time – 3J

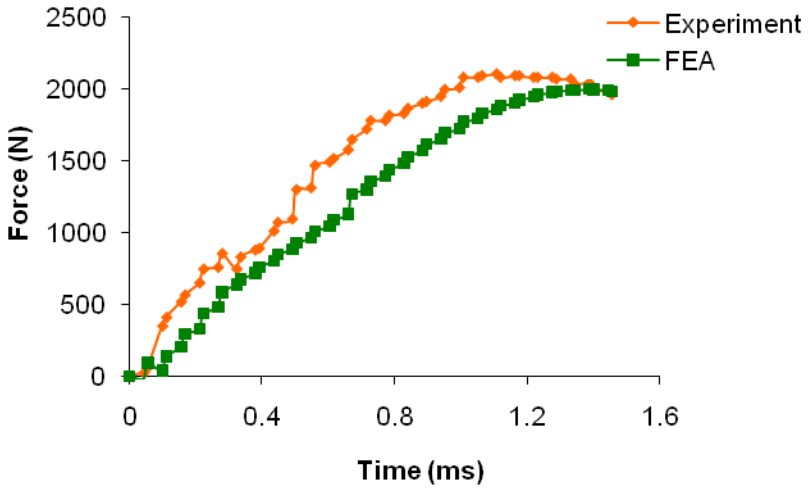


On Edge



Near Edge





- Good agreement between predicted and experimentally measured force/time curves for both On and Near edge impact.
- On Edge impact shows shorter impact time indicating higher stiffness of the laminate.
- Near Edge impact shows higher time duration indicating higher bending and flexural stresses.

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Edge Impact-Summary

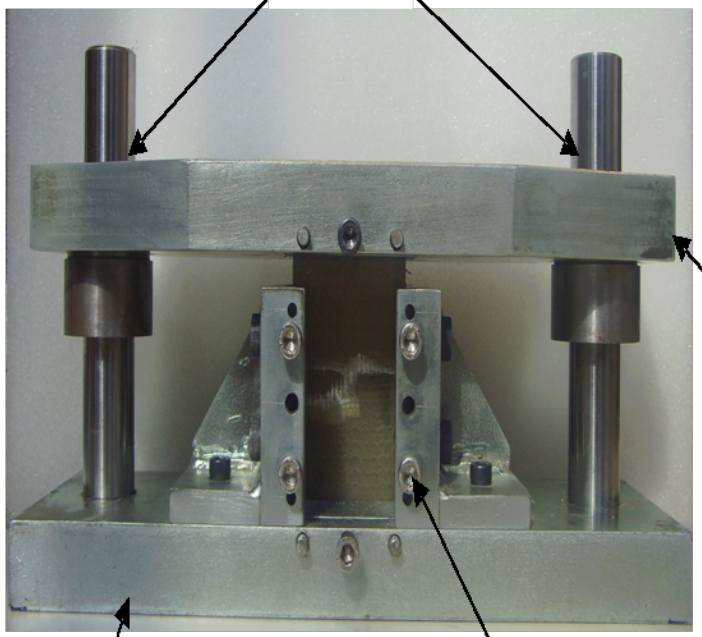
- On-edge impact leads to more fibre failure.
  - Observed from preliminary inspection of the damage
  - Higher stiffness is observed for On Edge impact from results.
  - Maximum stresses are more distributed through the thickness for on edge impact.

- Near Edge Impact Leads to more internal delamanation.
  - Observed from Maximum stresses that are found at the sites of observed delaminations for near edge impact.
  - Stresses are more distributed through the plane of the laminate.

Part II – Damage Tolerance
Compression Test Rig

Compression After Impact Test Machine

- Instron machine with 150 kN Load cell
- Queen Mary Compression After Impact Rig developed by Hogg et al.
- Crosshead speed was 0.5mm/min.



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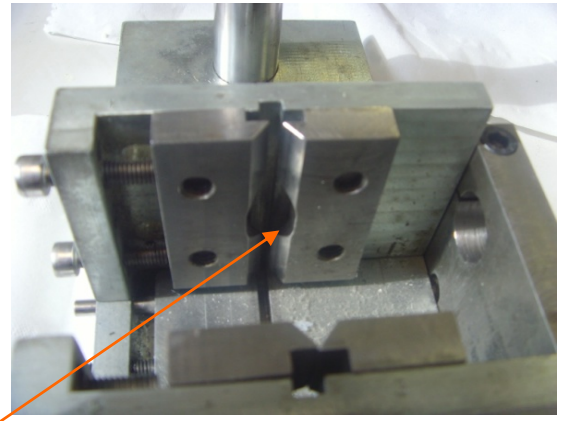
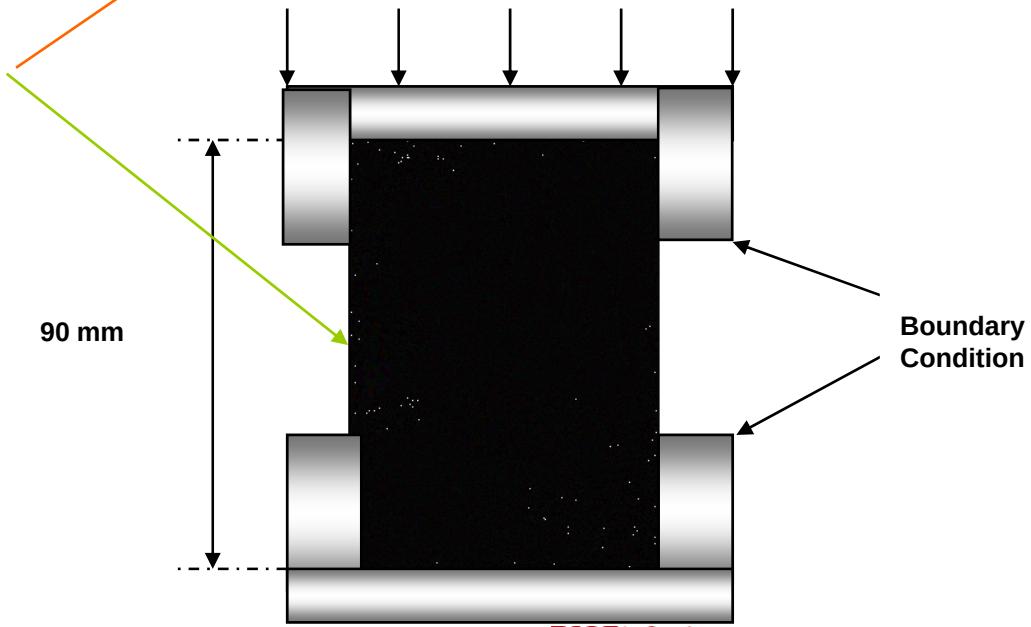
Boundary Condition

- Boundary conditions for edge impacted specimen
- Impacted damage zone and the opposite edge are not constrained.





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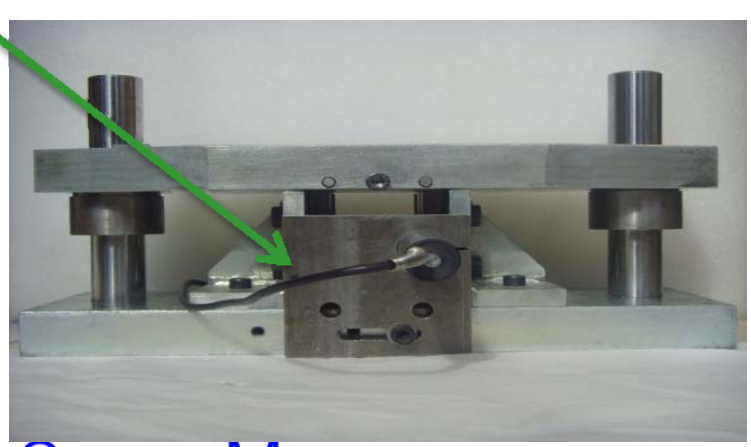
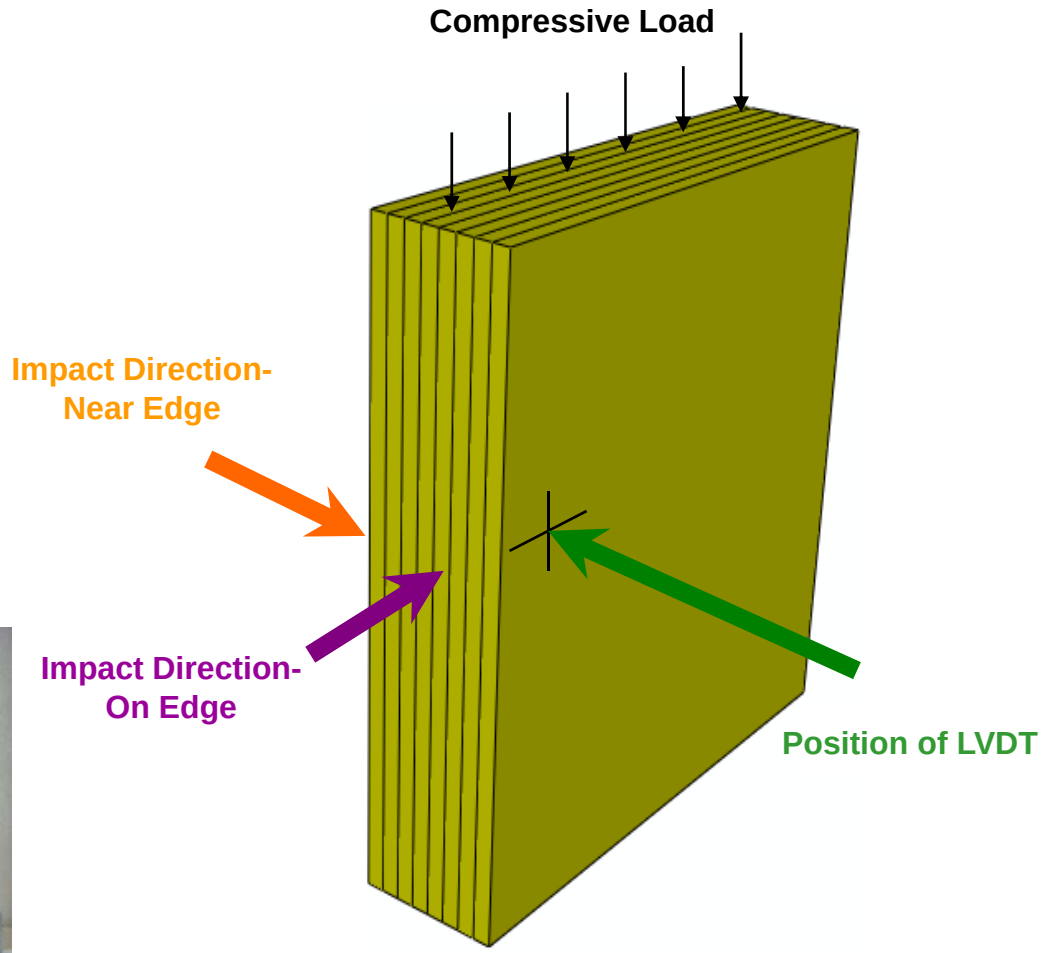
Position of LVDT

- Different buckling behaviours are analyzed for both types of edge impact.
- One LVDT is used at the back of laminate during compression after Edge Impact as shown in the figure.
- Figure below shows the Back position of LVDT





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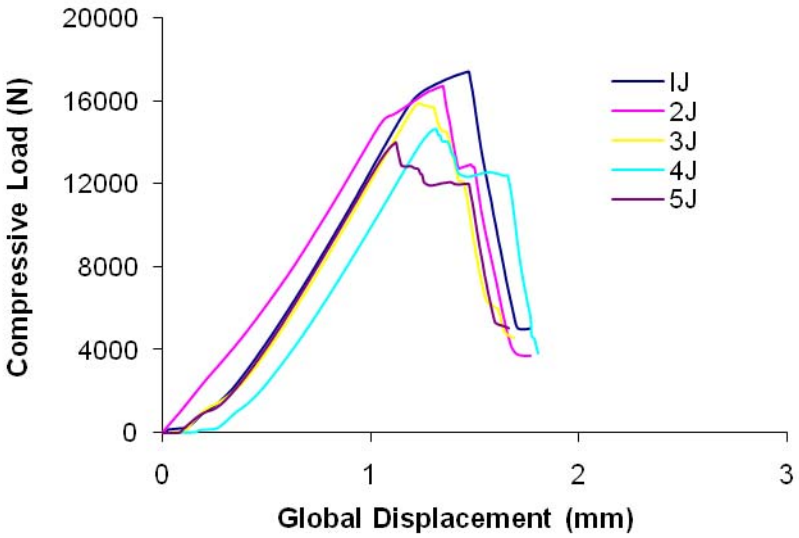
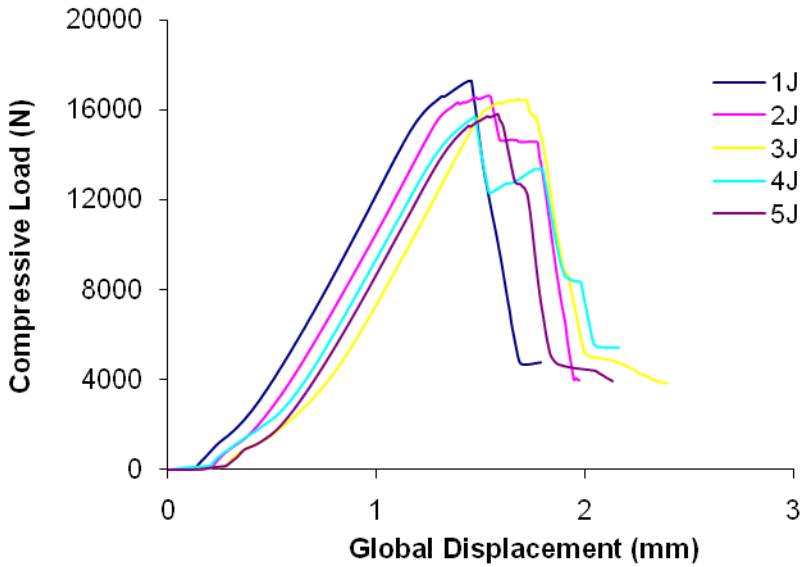
CAI Test Results:
Compressive Load Vs Global Displacement
-Thin Laminate (2mm)

Near Edge



On Edge



- On Edge impact shows more variation in compressive load and global displacement at different energy levels as compared to near edge impact.
- Reduced failure load for higher impact energy.
- Higher global displacement is seen for On edge Impact.

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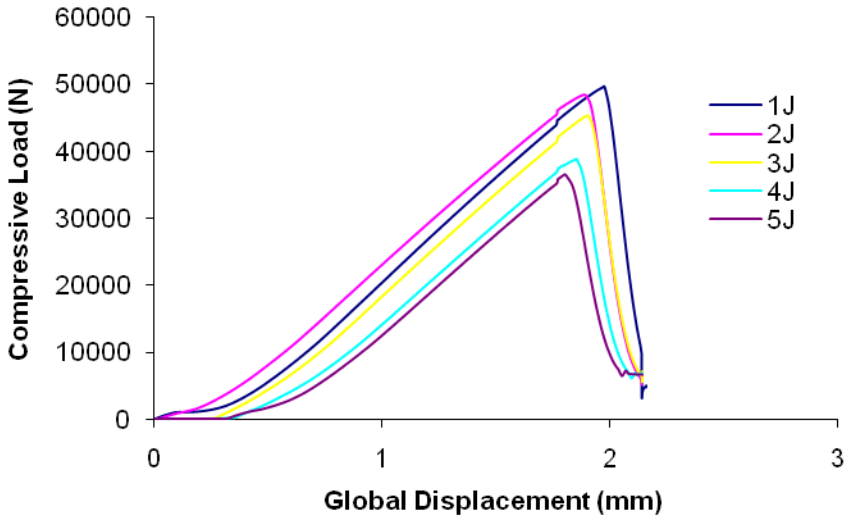
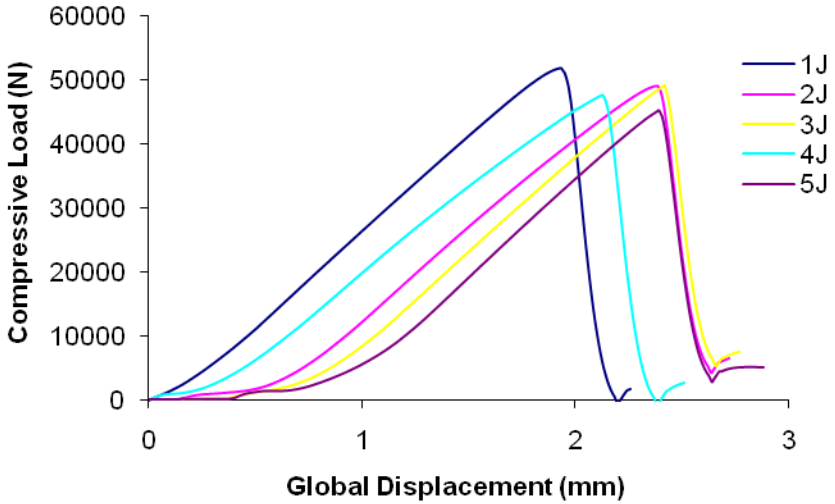
CAI Test Results:
Compressive Load Vs Global Displacement
-Thick Laminate (4mm)

Near Edge



On Edge



- On Edge impact shows large variation in global displacement at different energy levels.
- Higher global displacement is seen for On edge Impact.
- Near edge peak load and global displacement curves are smooth.

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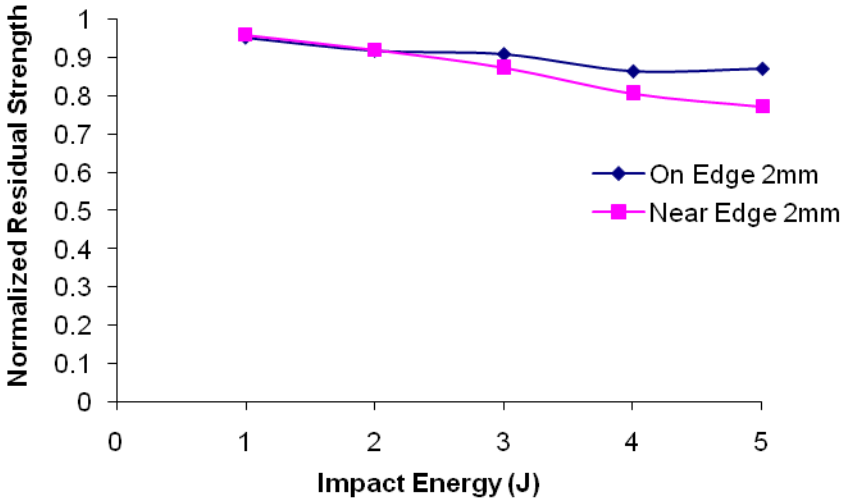
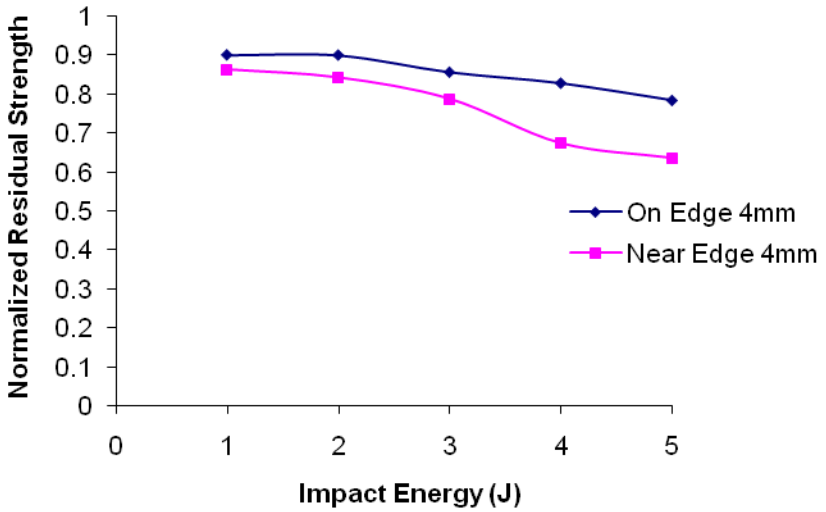
CAI Comparison of Results

Normalized Residual Strength Vs Impact Energy

Thin Laminate 2mm



Thick Laminate 4mm



- On Edge impact shows higher normalized residual strength at different thickness and energy levels as compared to near edge impact.
- Residual Strength decrease for near edge impact at higher energy levels

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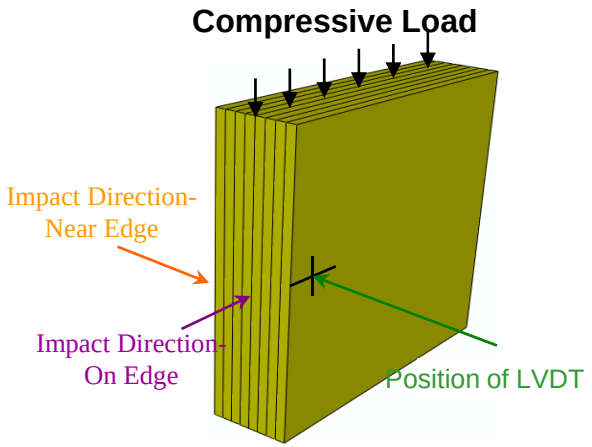
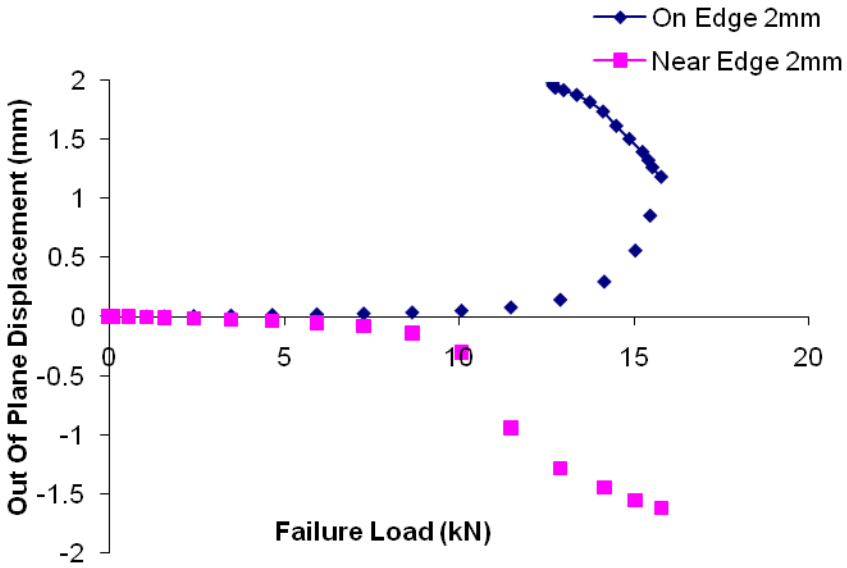
CAI Comparison of Results : 5J

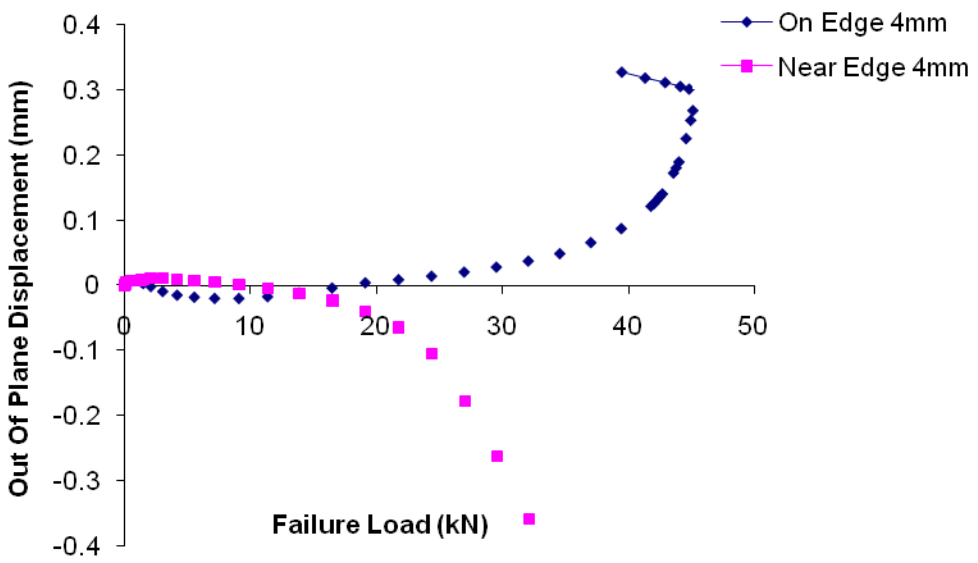
Out Of Plane Displacement Vs Failure Load



Thin Laminate- 2mm



Thick Laminate- 4mm



- Thin Laminates show higher out of plane displacement compared to thick laminate for both types of edge impact.
- Near edge impact is buckling concavely with respect to the impact damage.
- On Edge impact leads buckling in the opposite direction.

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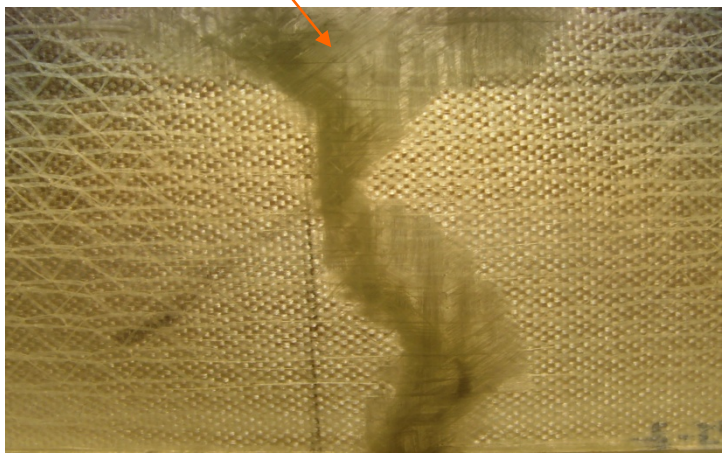
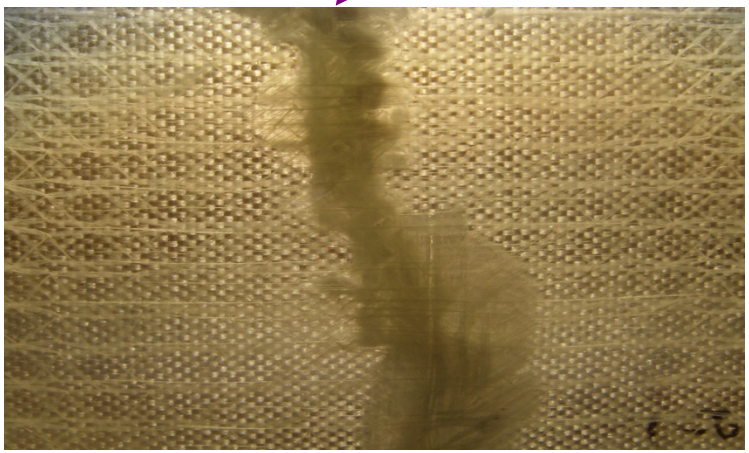
Damage Assessment :
Thickness 2mm and Energy Level 4J

Near Edge Impact Area



On Edge Impact Area



- Near Edge impact shows larger region of damage near the edge impact area.
- On edge Impact shows sharper damage propagation from the point of impact.

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Compression After Impact Test Results: Summary

- Near Edge Impact leads to lower residual strength in compression after edge impact.
  - Observed from normalized residual strength/Impact energy results.
  - Larger area of delamination is observed in the plane of the laminate.
- On Edge impact shows higher residual strength in compression after impact.
  - This damage may be critical for tension after impact.
  - Observed and predicted more fibre failure.

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Conclusions

- We have carried out an extensive edge impact and damage tolerance test programme for near edge and on edge impact on GFRP laminates.

- Edge impact leads to more concentrated damage but shows higher damage tolerance in compression-after-impact as compared to Near Edge Impact.
  - ❖ Later tests may include tension-after-impact.

- Finite element simulations can make very important contribution to understanding of impact damage and later models will include failure mechanisms.

Acknowledgements

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- Thanks for your attention !!!!!
- Any Questions ……???

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