Low Velocity Impact Damage to Carbon/Epoxy Laminates

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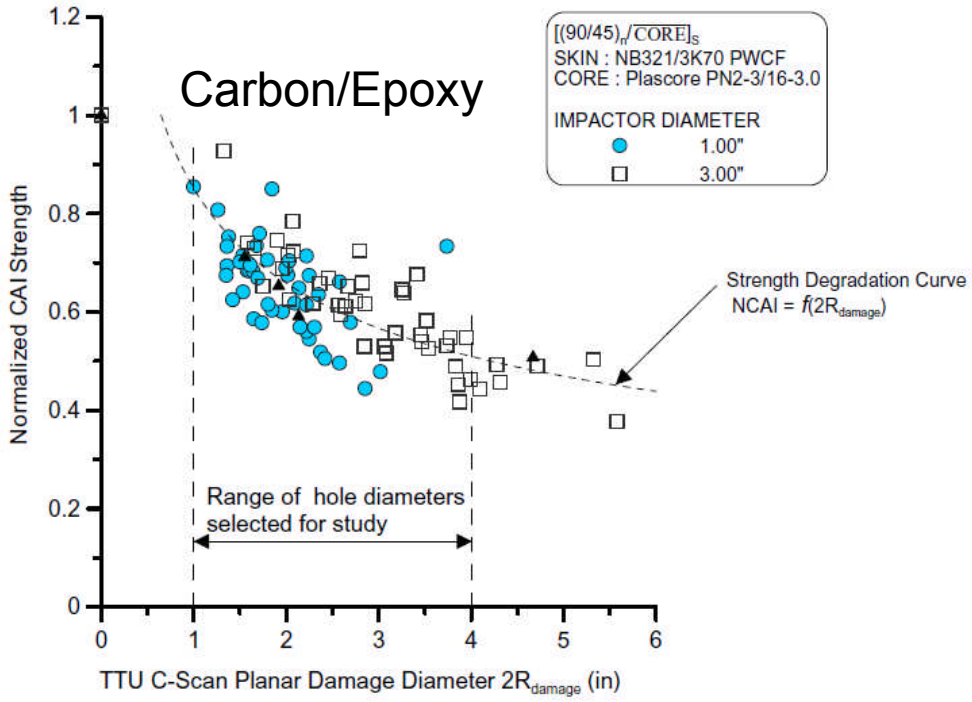
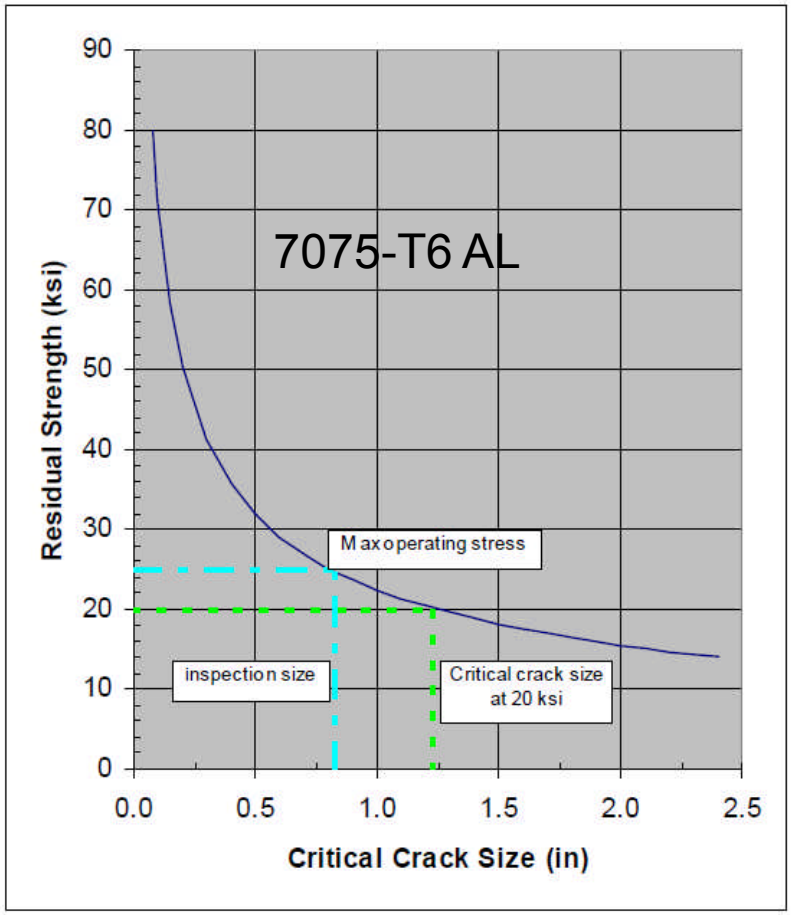
Why Look at Damage?

- No structure can be kept “damage free”
- Even small damages may cause large strength drops

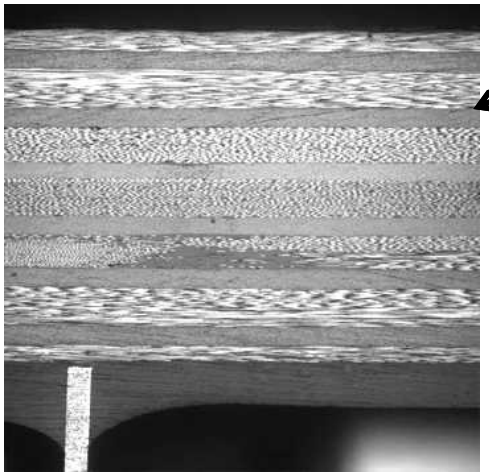
True for Composites and Metals





Basic Concepts

Foreign Object Impact Can Cause Subsurface Damage in Laminates

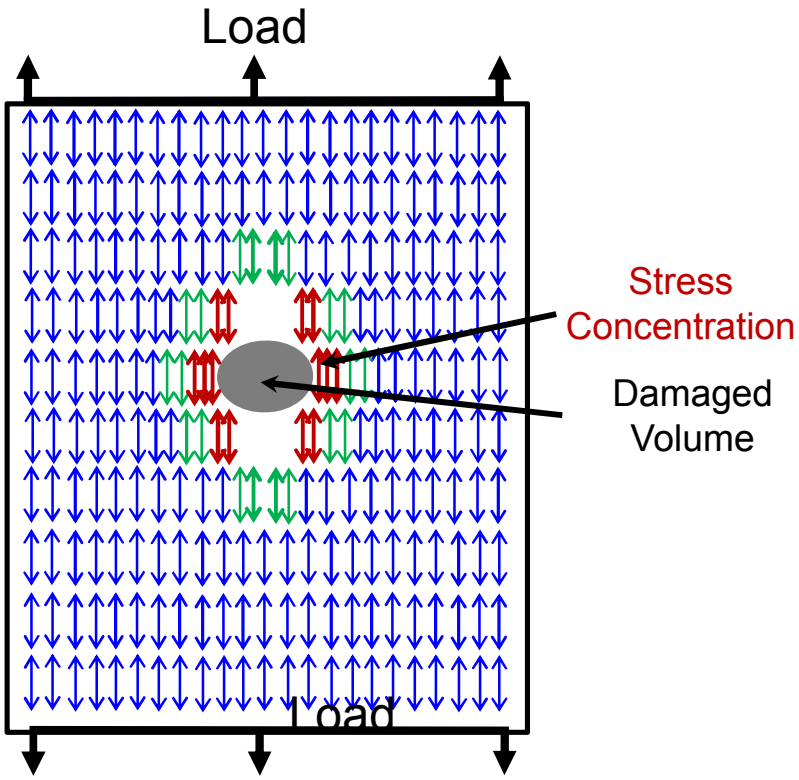


Undamaged laminate

Laminate Hit by 6.4 mm diameter Object with 2.1 Joules of Energy

Basic Concepts

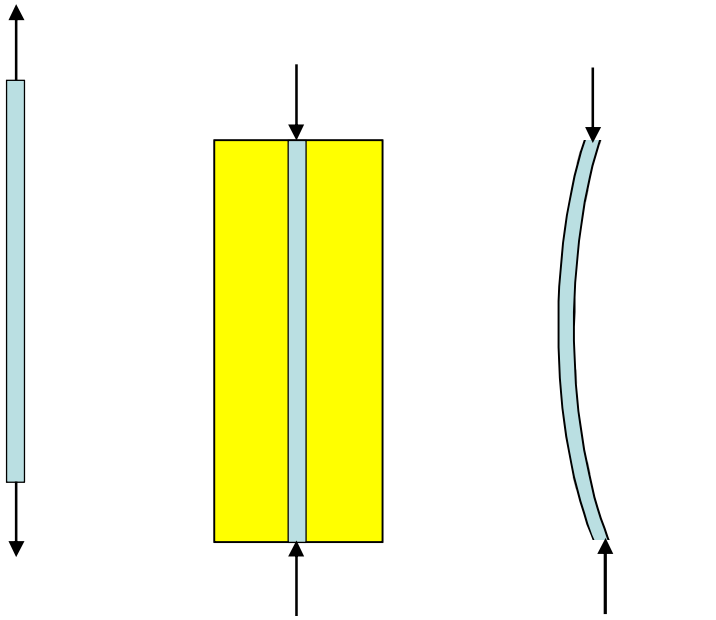
Damaged Material May not Carry Load resulting in a Stress Concentration



In General:

Tensile load requires fiber to be intact

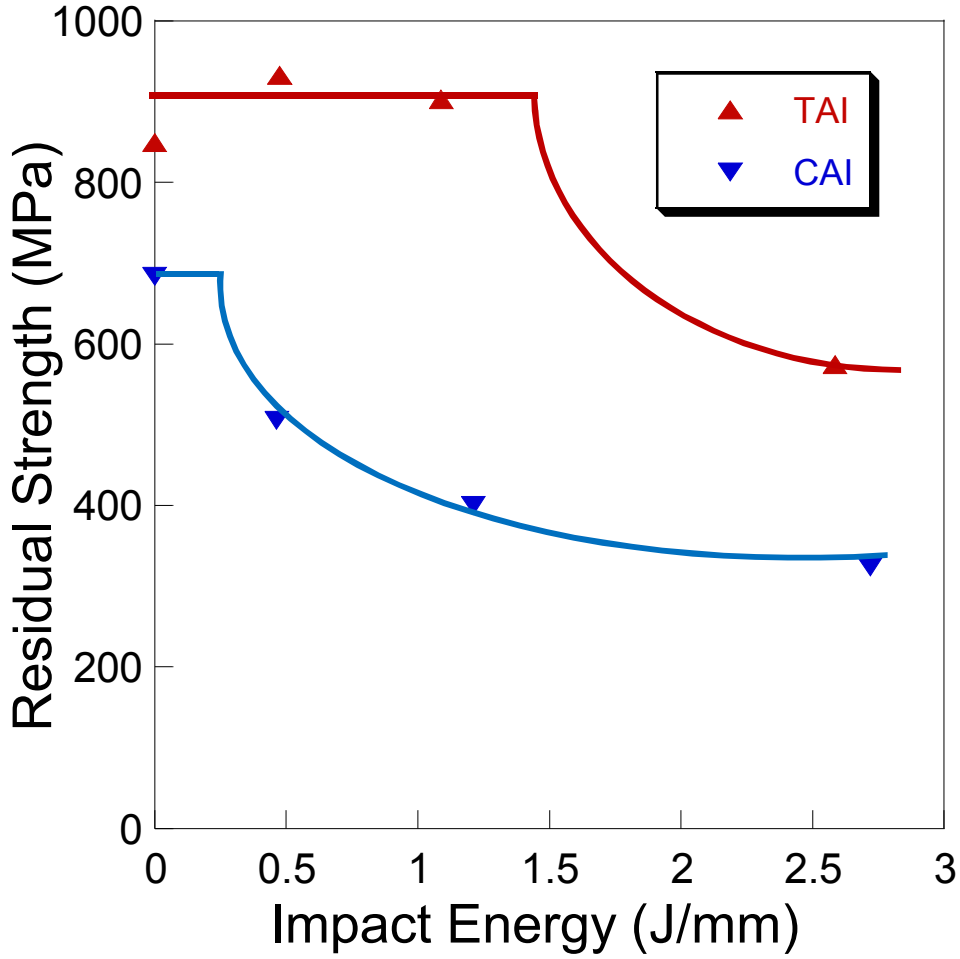
Compression load requires fiber to be intact **and** matrix to stabilize fiber



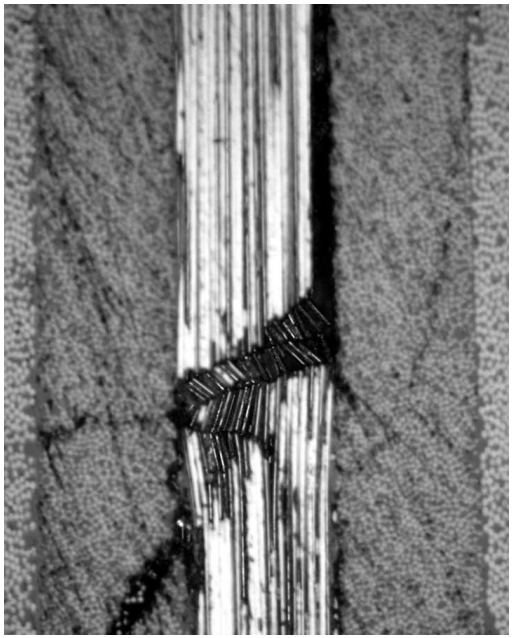
Basic Concepts

Compressive Loads With Impact Damage a Big Concern

Combination of Stress Concentration and Matrix Damage from Impact Tends to Cause Localized Fiber Buckling

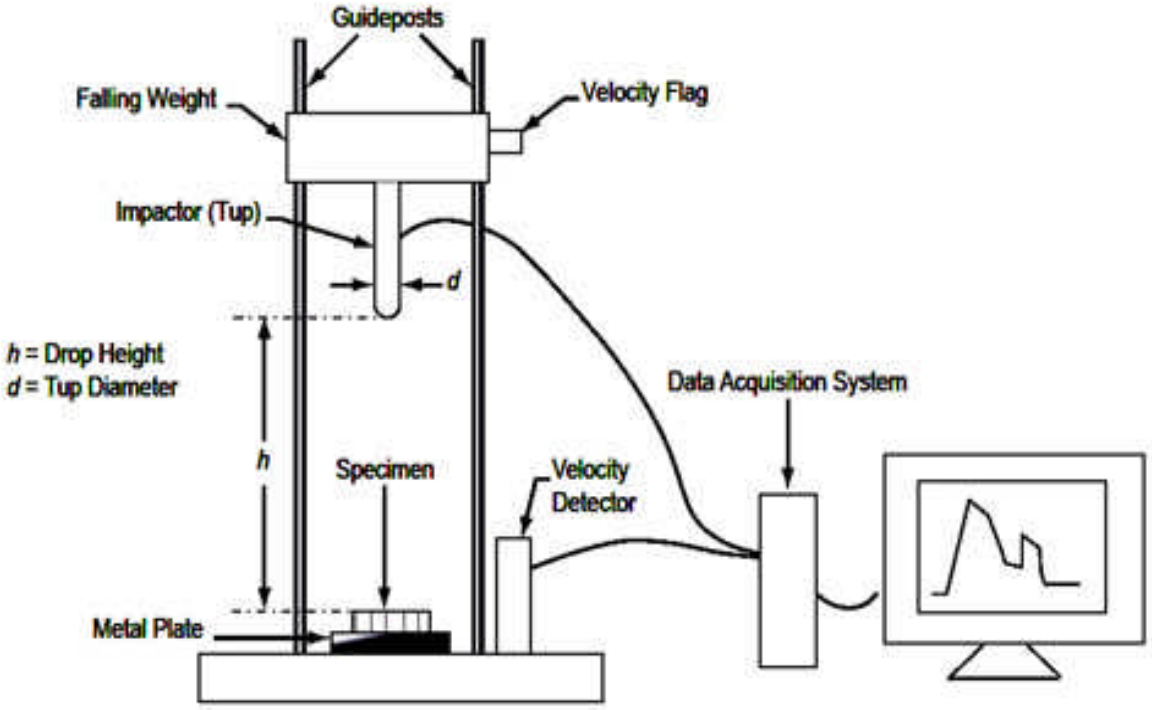


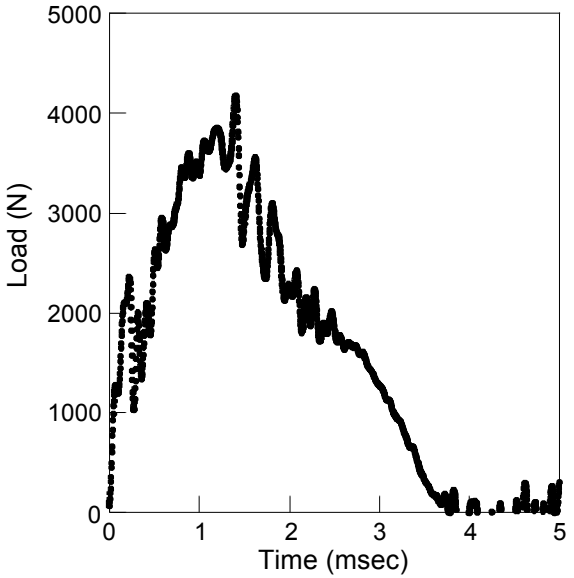
Local Fiber Buckling



Damage Tolerance Testing

Impacting a Laminate to Produce Damage:



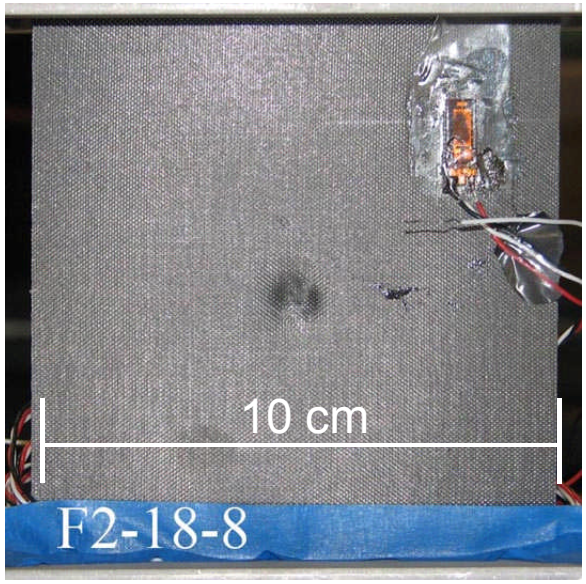


Instrumented Drop weight Apparatus

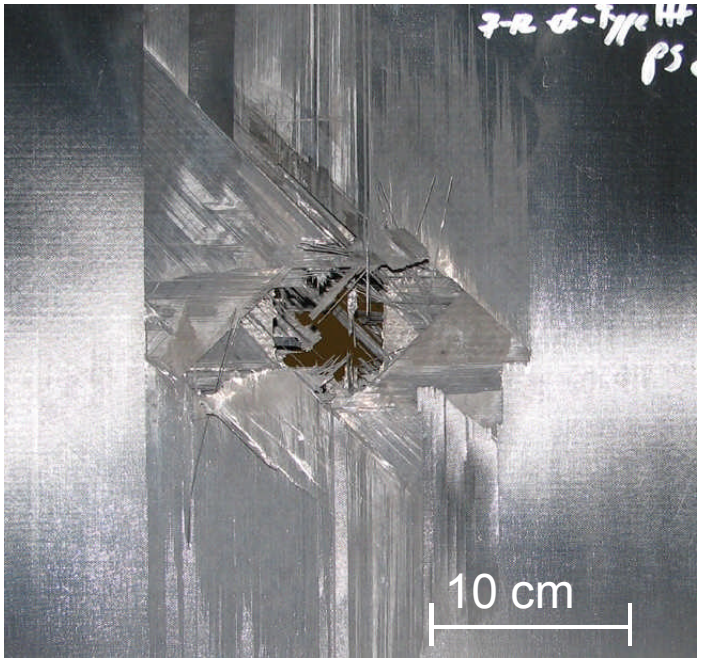
Damage Tolerance Testing

Assessing damage to an impacted laminate:

Most common technique is visual inspection. Criticality is very industry/use specific



This impact may be acceptable for some airplanes, but not acceptable for launch vehicles

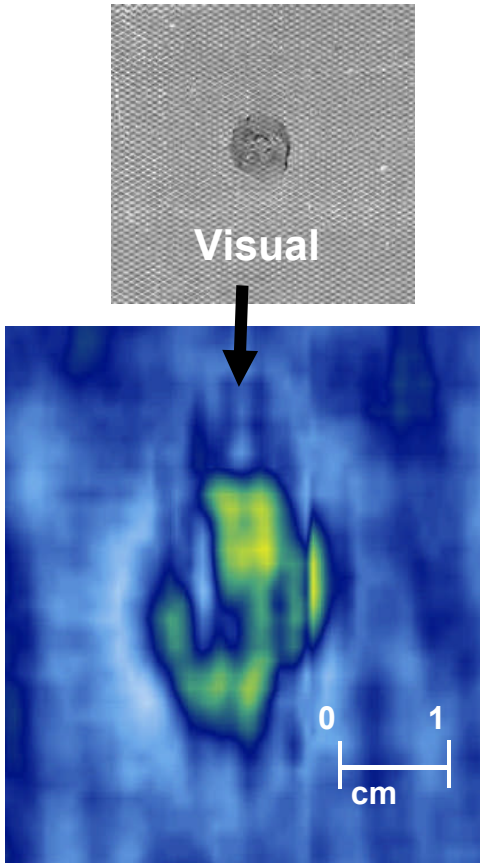


Some fighter aircraft may need to fly with this sort of damage

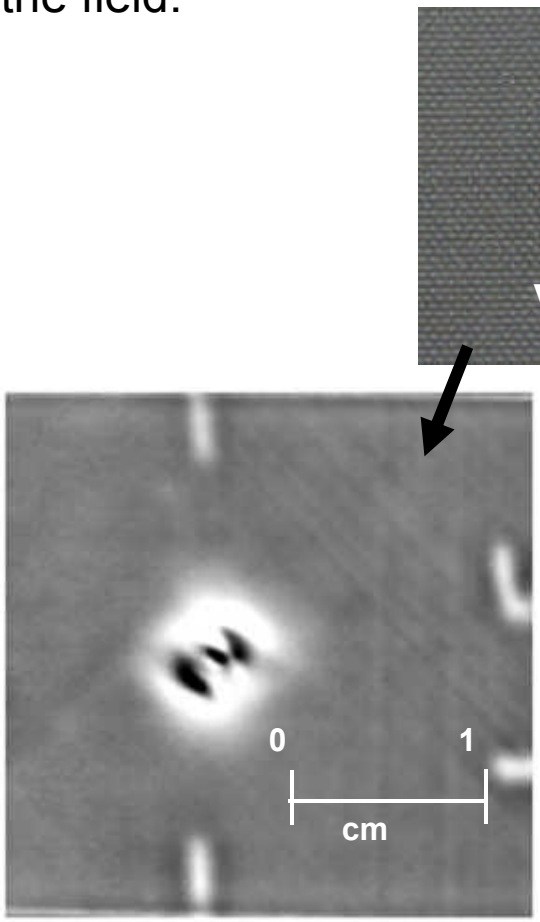
Damage Tolerance Testing

Assessing damage to an impacted laminate:

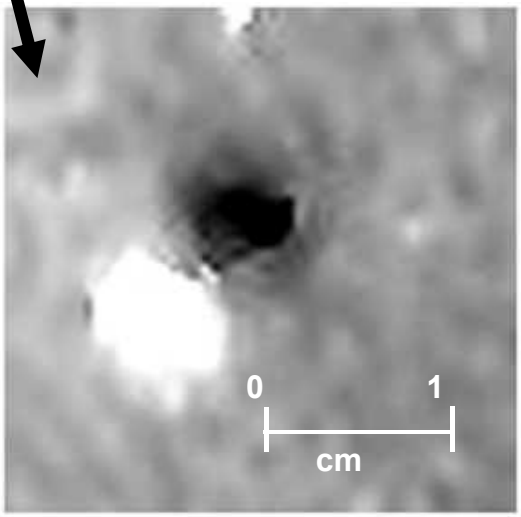
Non-Destructive Evaluation (NDE) is most beneficial as most of these techniques can be used in the field.



Ultrasonic



Thermography

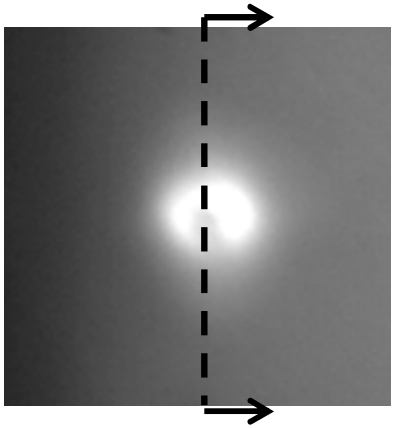


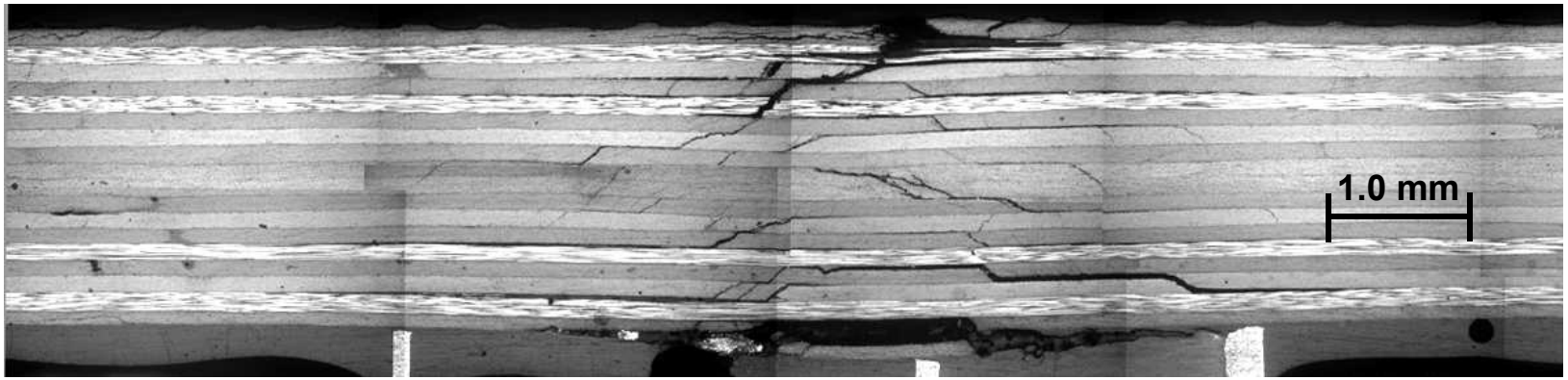
Shearography

Damage Tolerance Testing

Assessing damage to an impacted laminate:

Destructive evaluation is needed to interpret the NDE results.





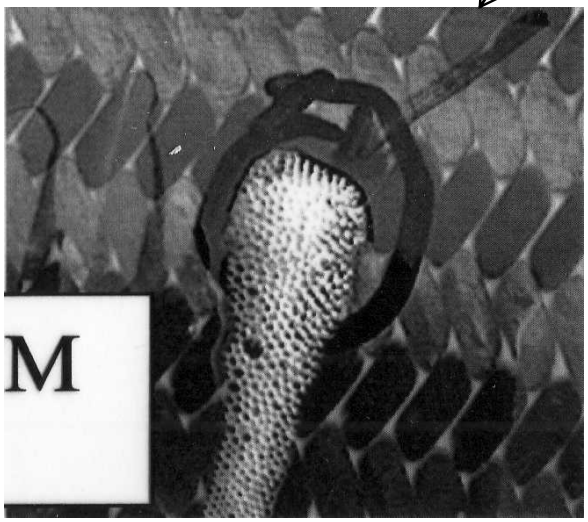
Cross-sectional examination gives indication of through the thickness damage

Damage Tolerance Testing

Testing after impact: Most often Compression After Impact (CAI) is of interest.

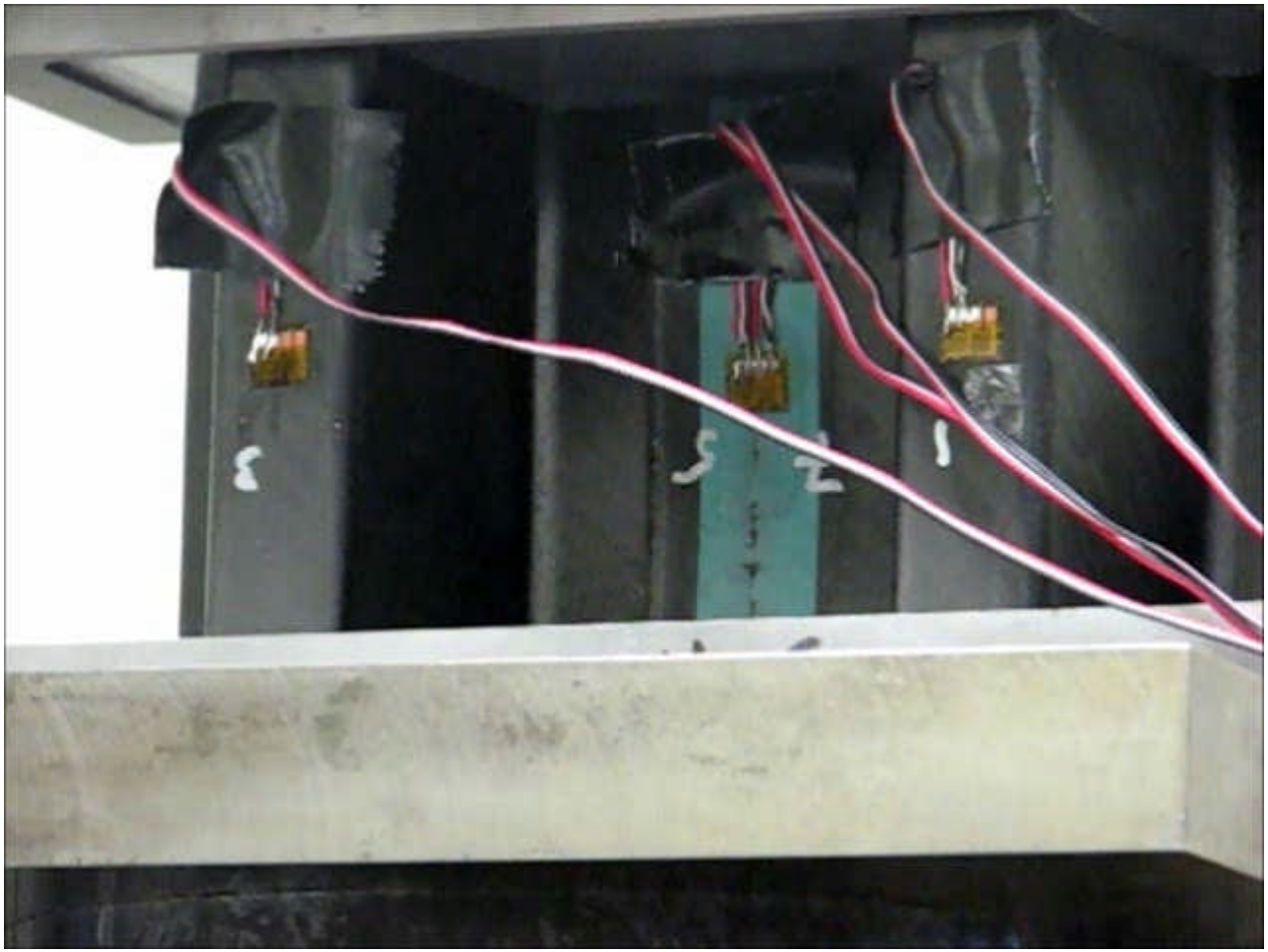
Other properties may be of interest depending upon the application

- Tension – (Pressure vessels, Rocket motor cases)
- Shear – (Fuselage sections)
- Leakage – (Fuel tanks, feedlines, piping)



Damage Tolerance Testing

Compression after impact testing:



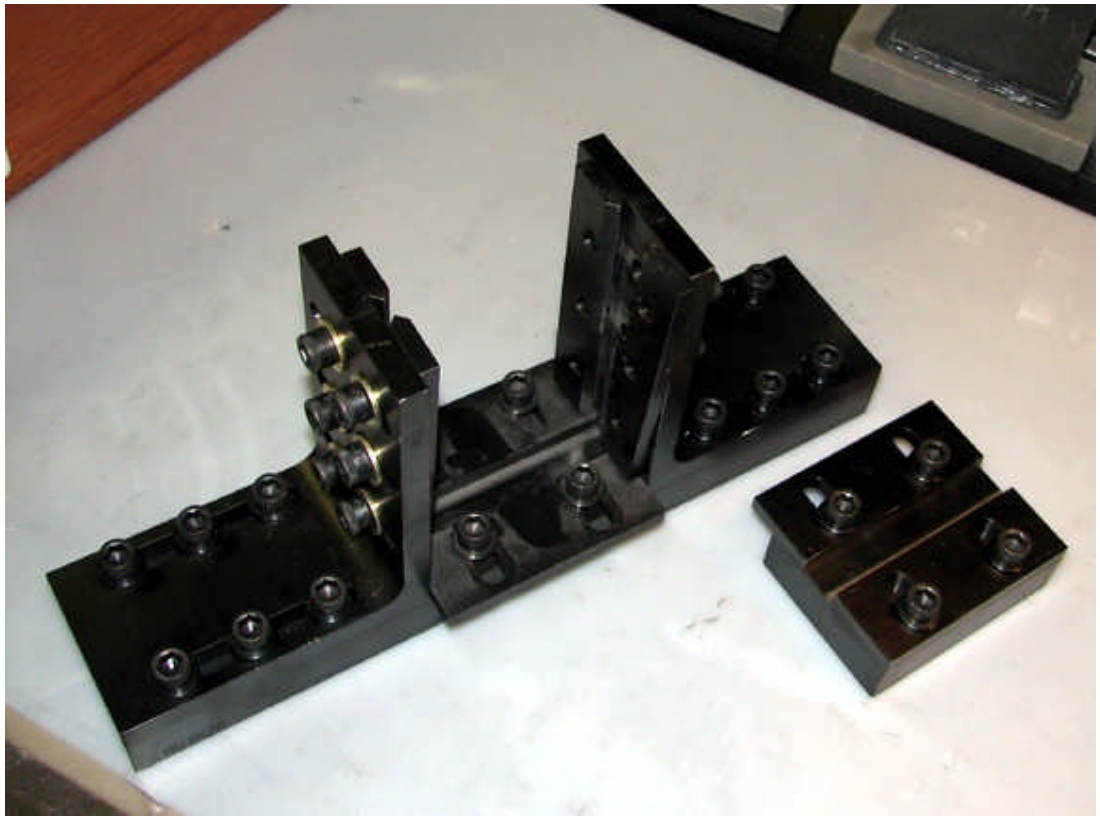
Damage Tolerance Testing

Compression after impact testing:

ASTM Standard D-7137 - *Standard Test Method for Compressive Residual Strength Properties of Damaged Polymer Matrix Composite Plates.*

Specimen to be damaged per ASTM D 7136:

- 6.7 J/mm Impact Energy
- 100 by 150 mm rectangle
- Clamped over a 75 by 125 mm rectangular opening
- 16 mm diameter impactor
- 5.5 kg drop mass
- $[45/0/-45/90]_{NS}$ lay-up



Damage Tolerance Testing

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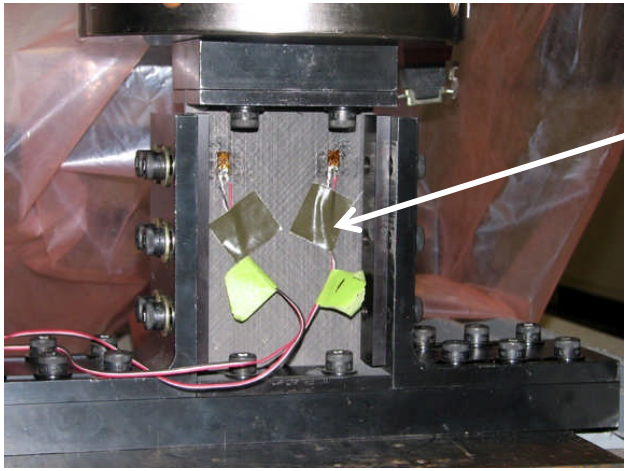
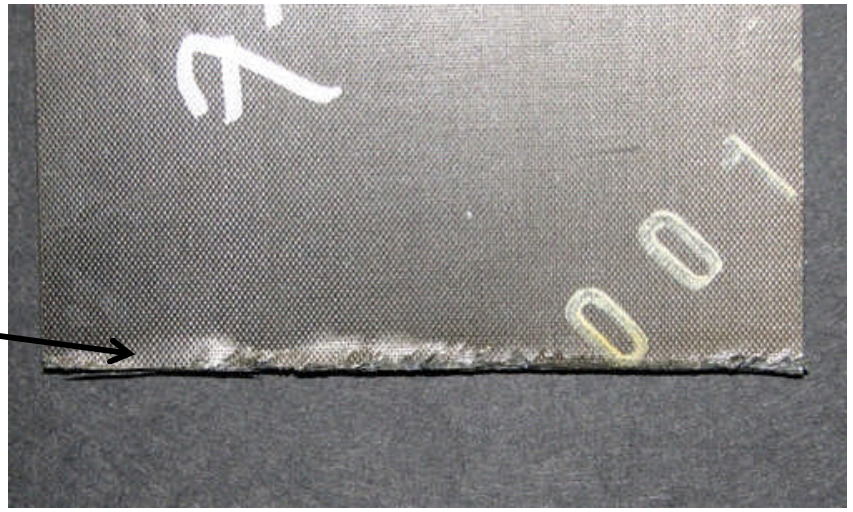


Specimen must be damaged such that "*End Brooming*" failures do not occur.

Example of "*End Brooming*"

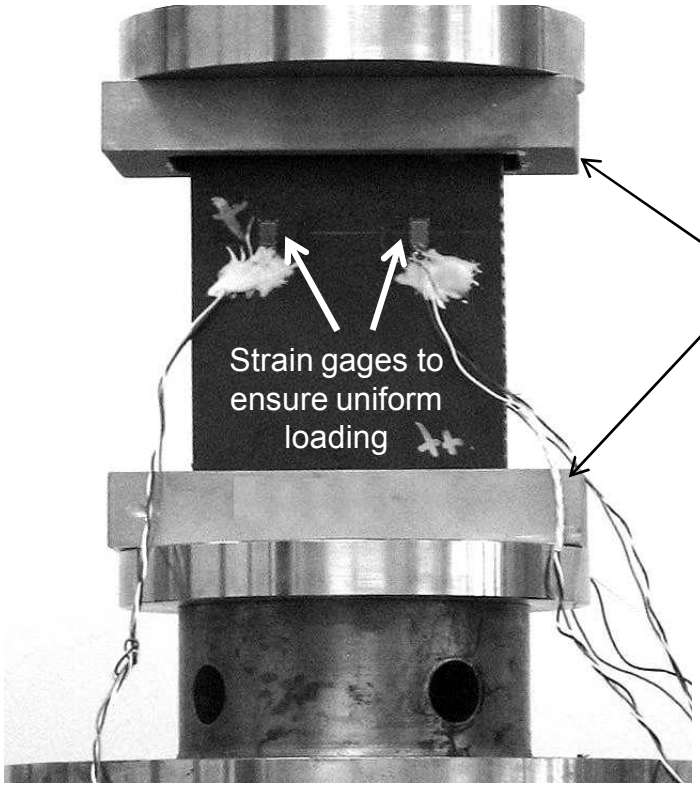
Unacceptable failure mode



Damage Tolerance Testing

Compression after impact testing:
A more costly, but versatile method is to pot the ends.

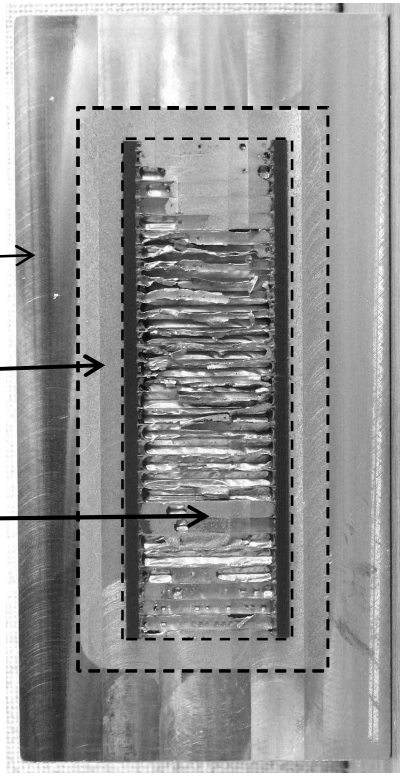
Sandwich Structure



Aluminum Frames

Potting Compound (typically epoxy)

Specimen



Damage Tolerance Testing

Compression after impact testing:
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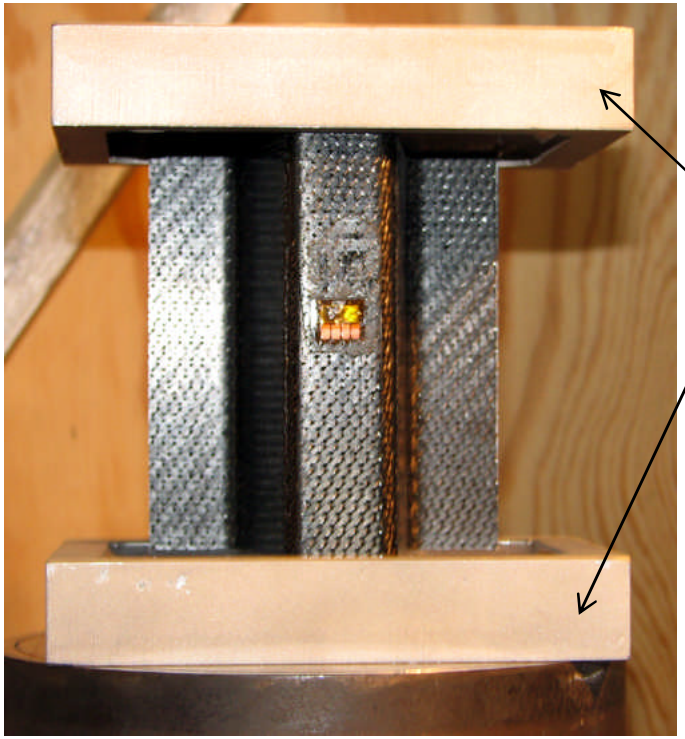
Hat Stiffened Structure



Aluminum Frames

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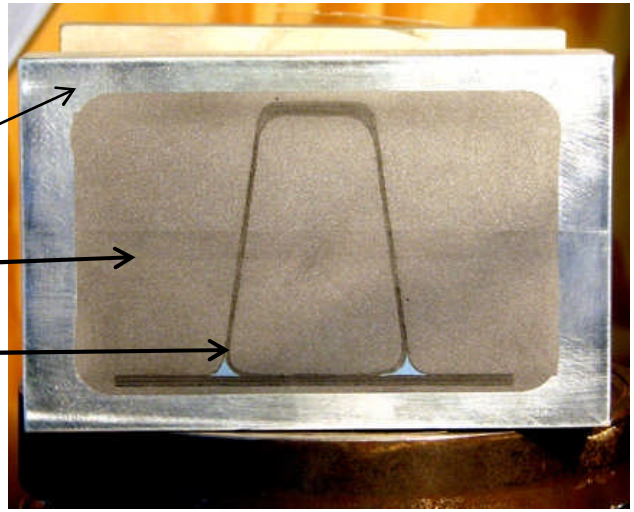
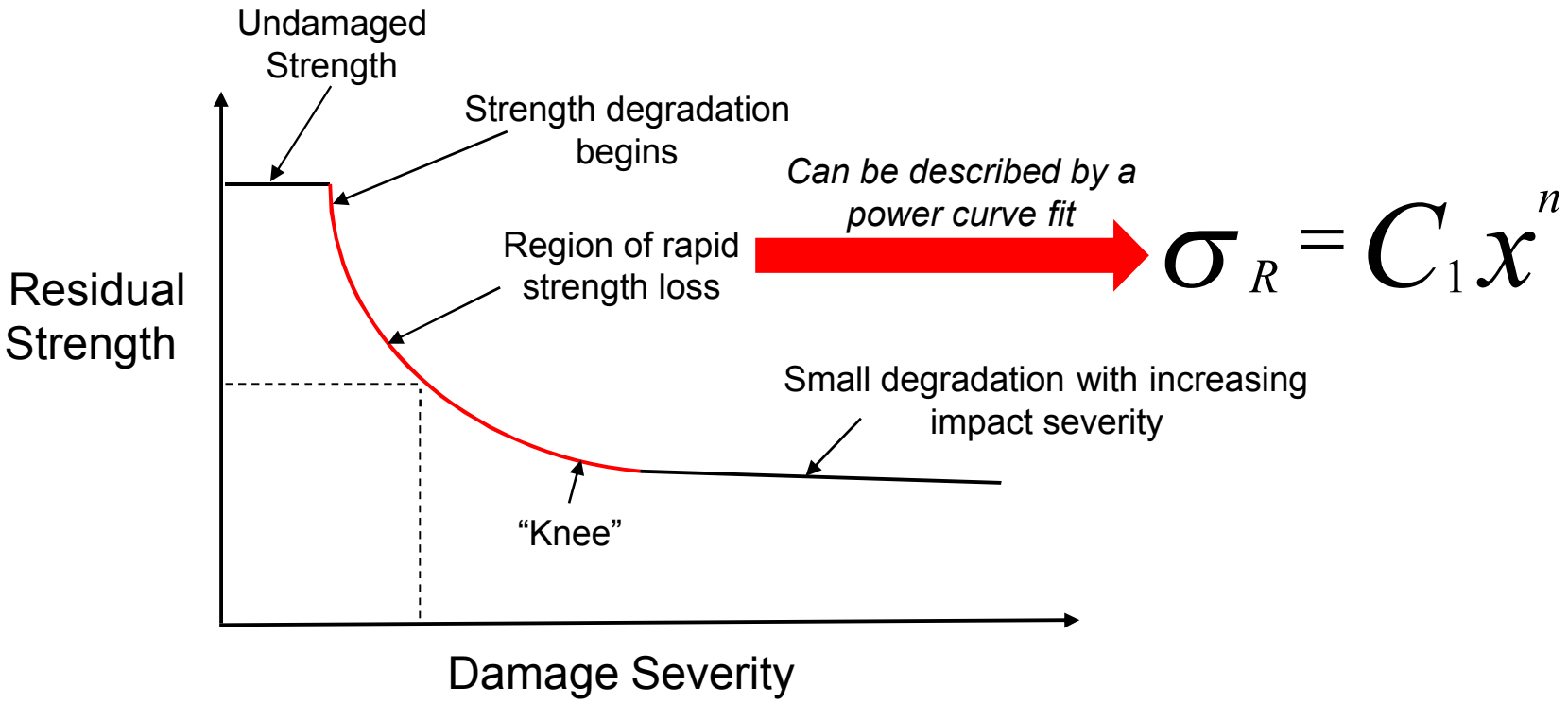


Damage Tolerance Testing

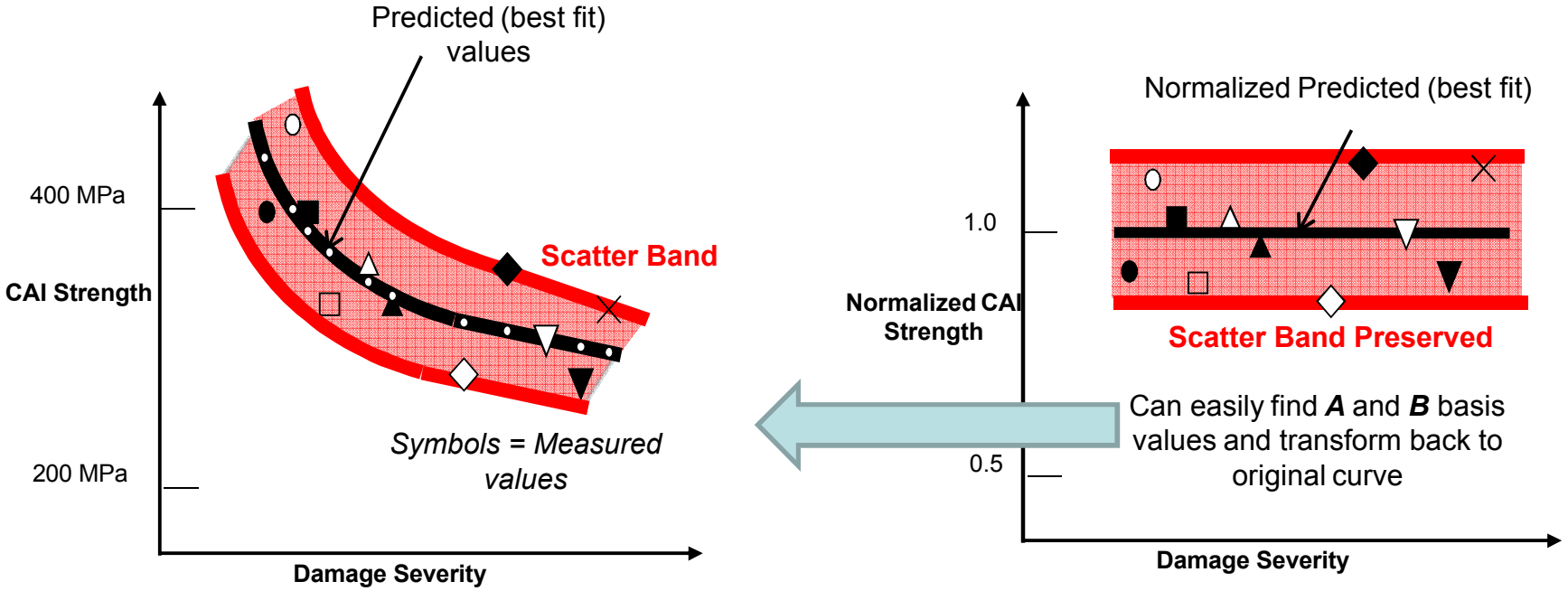
Reduction of data:
Typically construct plots of residual strength versus damage severity.



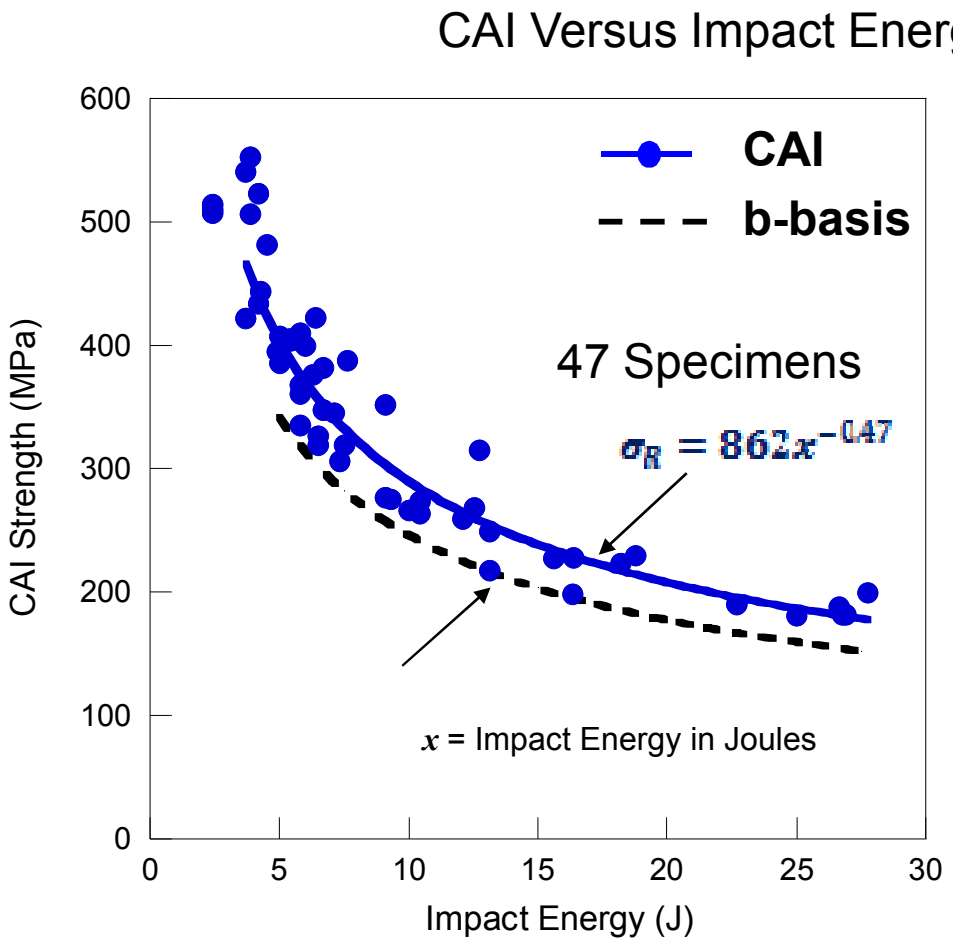
Damage Tolerance Testing

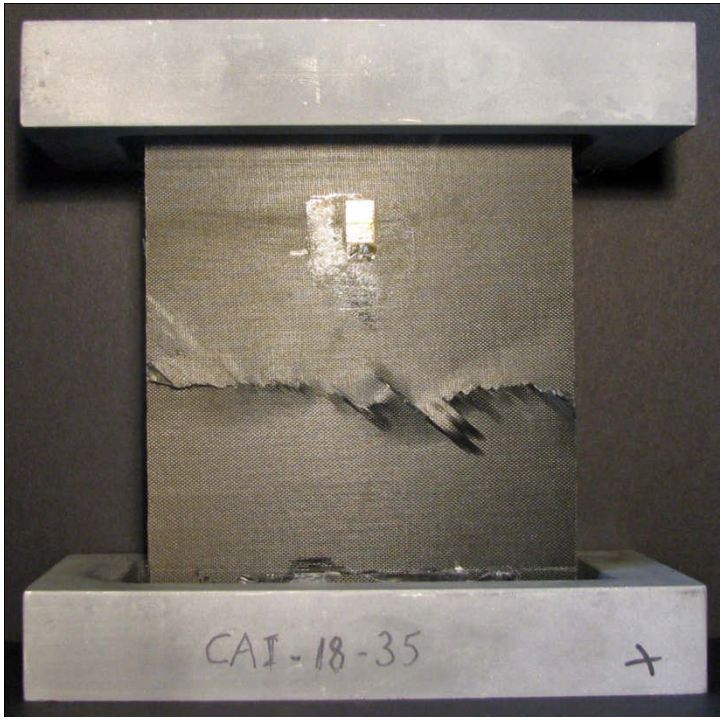
Reduction of data:
Fit data in strength reduction portion of curve to a power law. These are the "predicted" values.

Normalize data by dividing Measured value by its corresponding "Predicted" value.



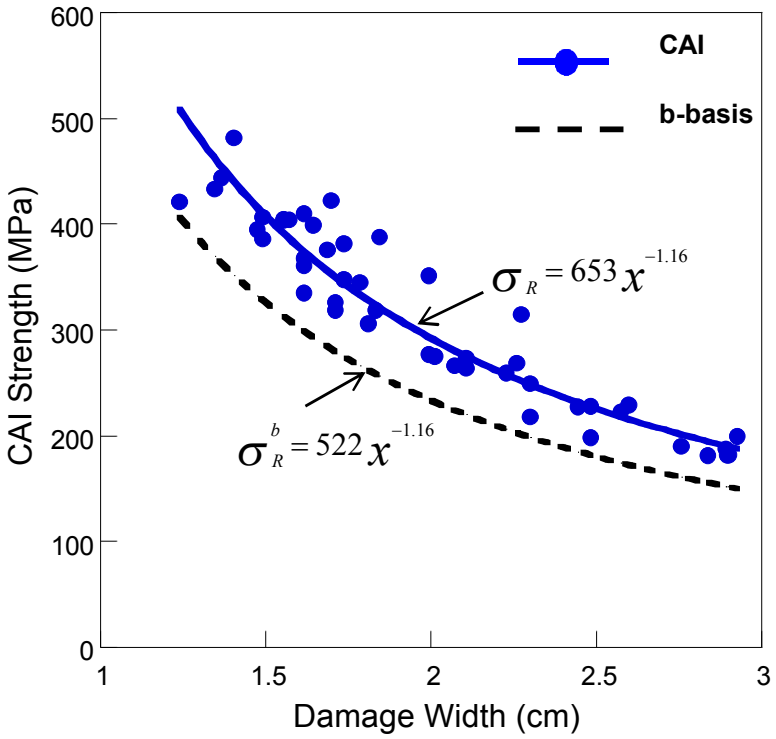
Examples from MSFC



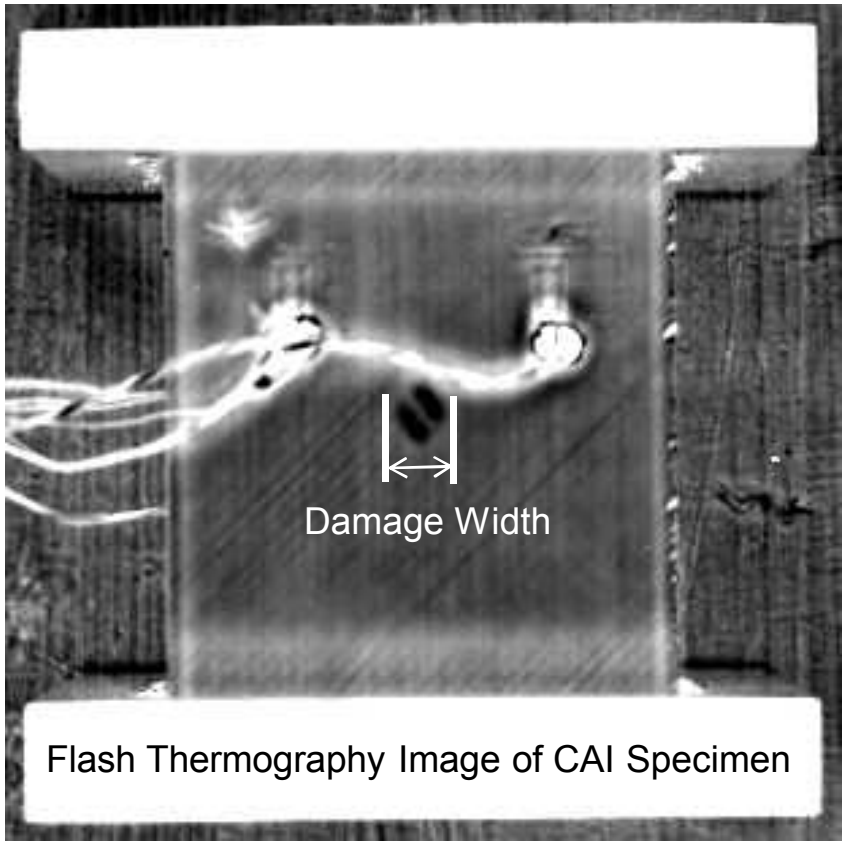


Examples from MSFC

CAI Versus Impact Damage Width



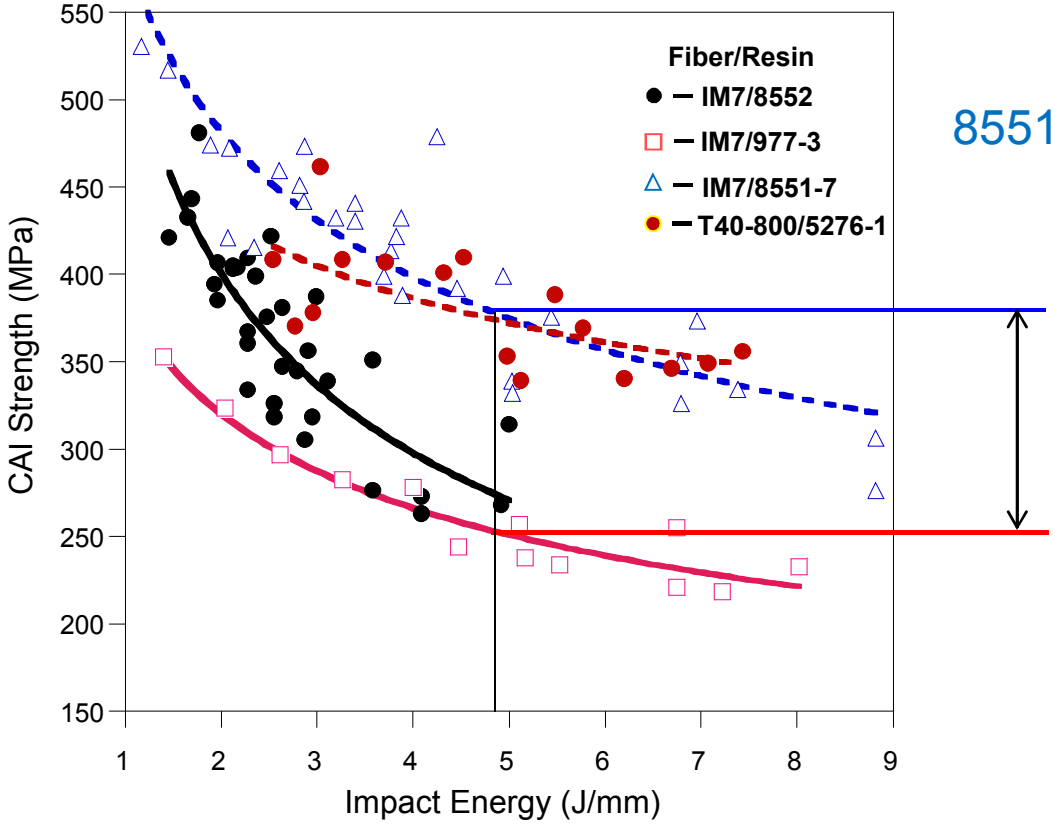
As measured by Flash Thermography



Flash Thermography Image of CAI Specimen

Examples from MSFC

CAI Strength of Various Resin Systems

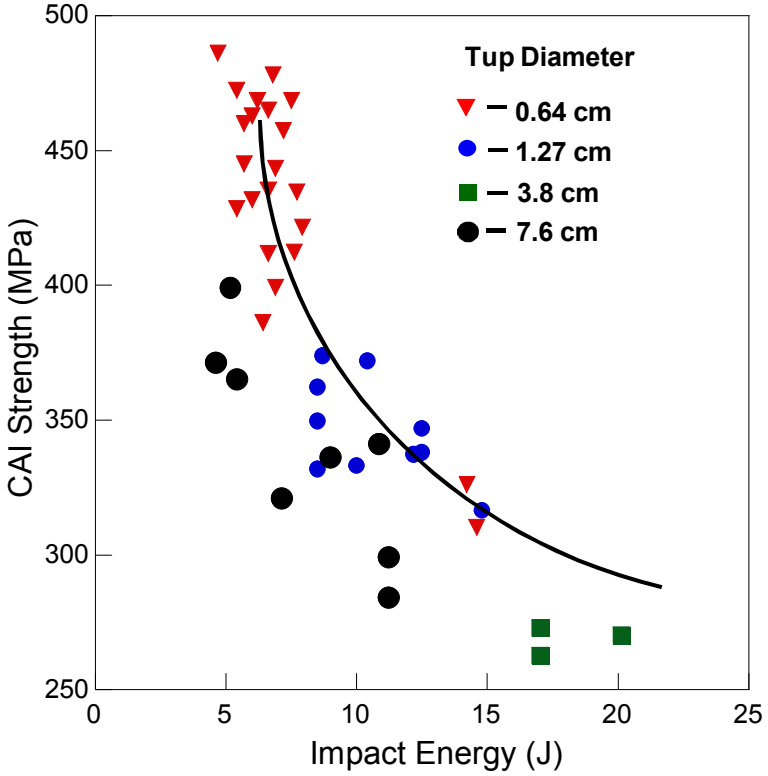


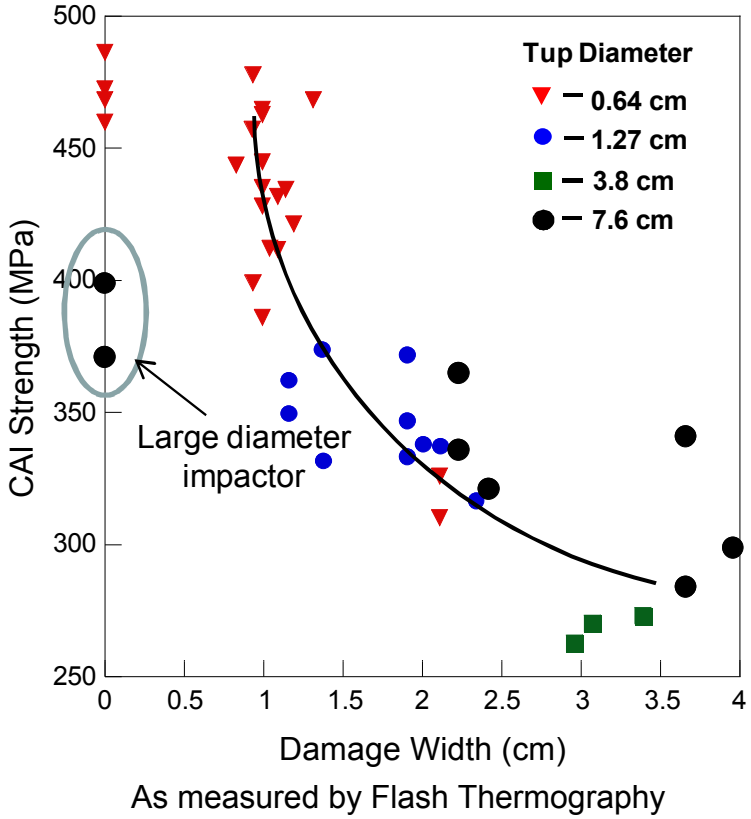
8551-7 => Rubber Toughened
Poor Hot/Wet

However;
If your structure will not see hot/wet then much margin can be gained.

Examples from MSFC

CAI Strength Versus Impactor Size

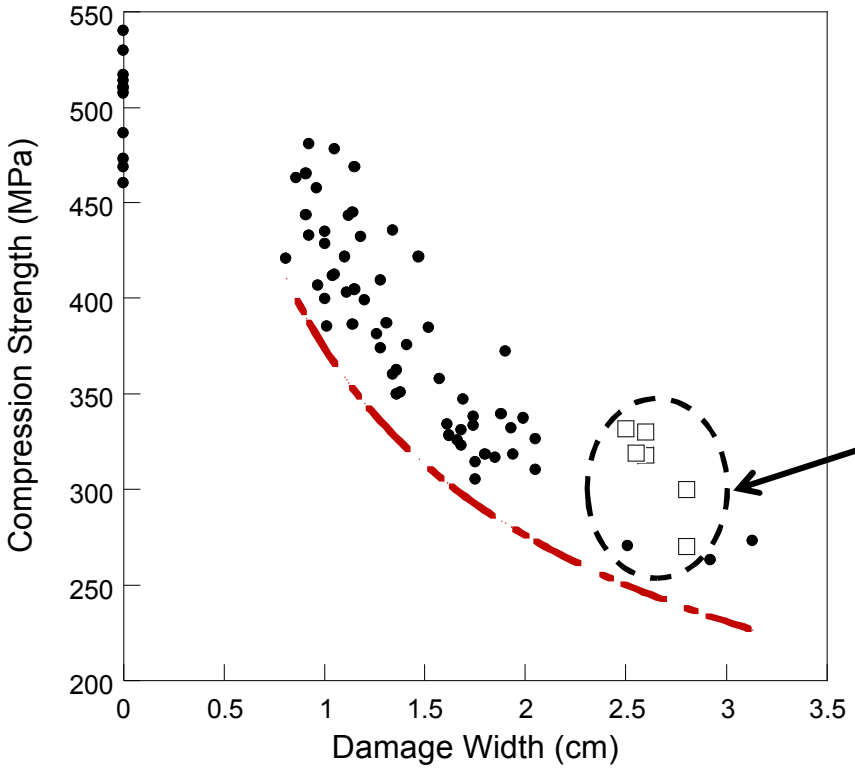


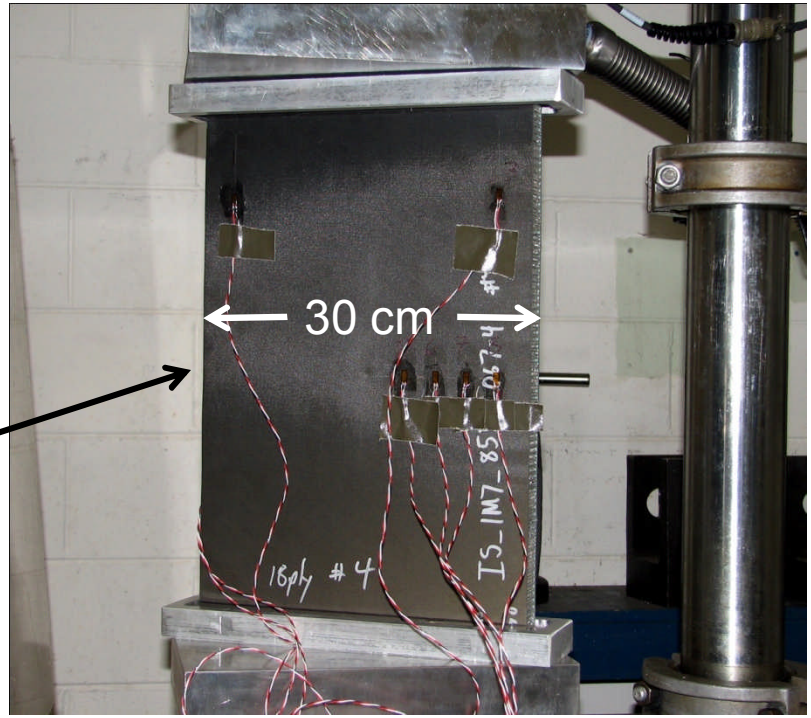


As measured by Flash Thermography

Examples from MSFC

Check for Scalability issues.





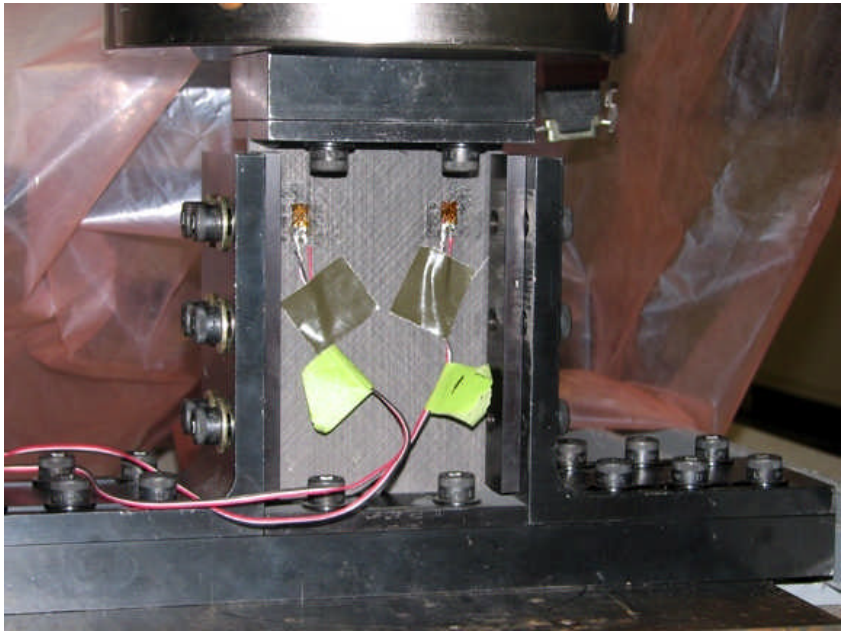
For sandwich structures, smaller specimens tend to be slightly conservative[1]

1. Moody, R.C., Harris, J.S. and Vizzini, A.J. (2002). Scaling and Curvature Effects on the Damage Tolerance of Impacted Composite Sandwich Panels. *Journal of Sandwich Structures and Materials*, **4**: 71-82.

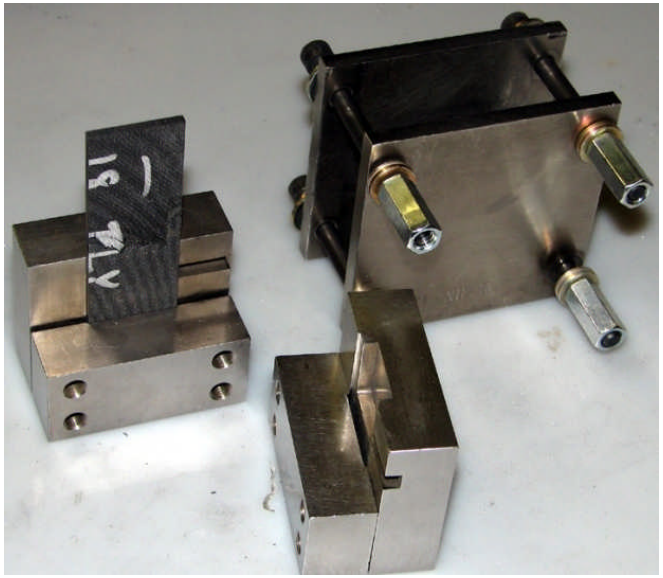
Examples from MSFC

Problems with using Uniform Knockdown Factors

Test Data from IM7/8552 $[45/0/-45/90]_{NS}$



σ^{c}_{Avg} = 213 MPa

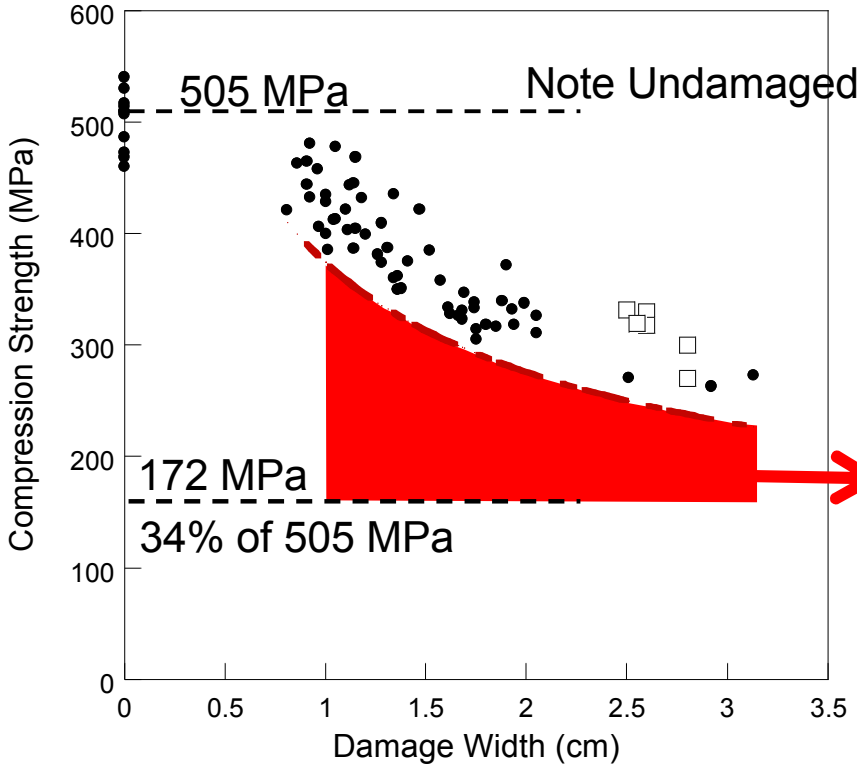


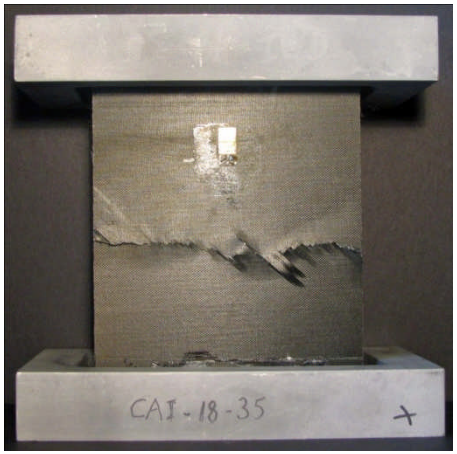
σ^{c}_{Avg} = 628 MPa

Damaged Strength = 213/628 = 34% Pristine

Examples from MSFC

Problems with using Uniform Knockdown Factors





Unnecessary conservatism. May be OK if weight is not an issue

- *Un-notched strength is more of a test of the test method.*
- Difficult to avoid invalid failures. Notched laminates fail at stress concentration which makes testing easier and less costly

Conclusions

- Impact damage tends to be more detrimental to a laminate's compression strength as compared to tensile strength
- Proper use of Non Destructive Evaluation (NDE) Techniques can remove conservatism (weight) from many structures
- Test largest components economically feasible as "coupons"
- If damage tolerance is a driver, then consider different resin systems
- Do not use a single knockdown factor to account for damage