IMPROVING DELAMINATION RESISTANCE AND STIFFNESS-RETENTION IN THICK SECTION COMPOSITES USING COMPLIANT INTERLAYERS

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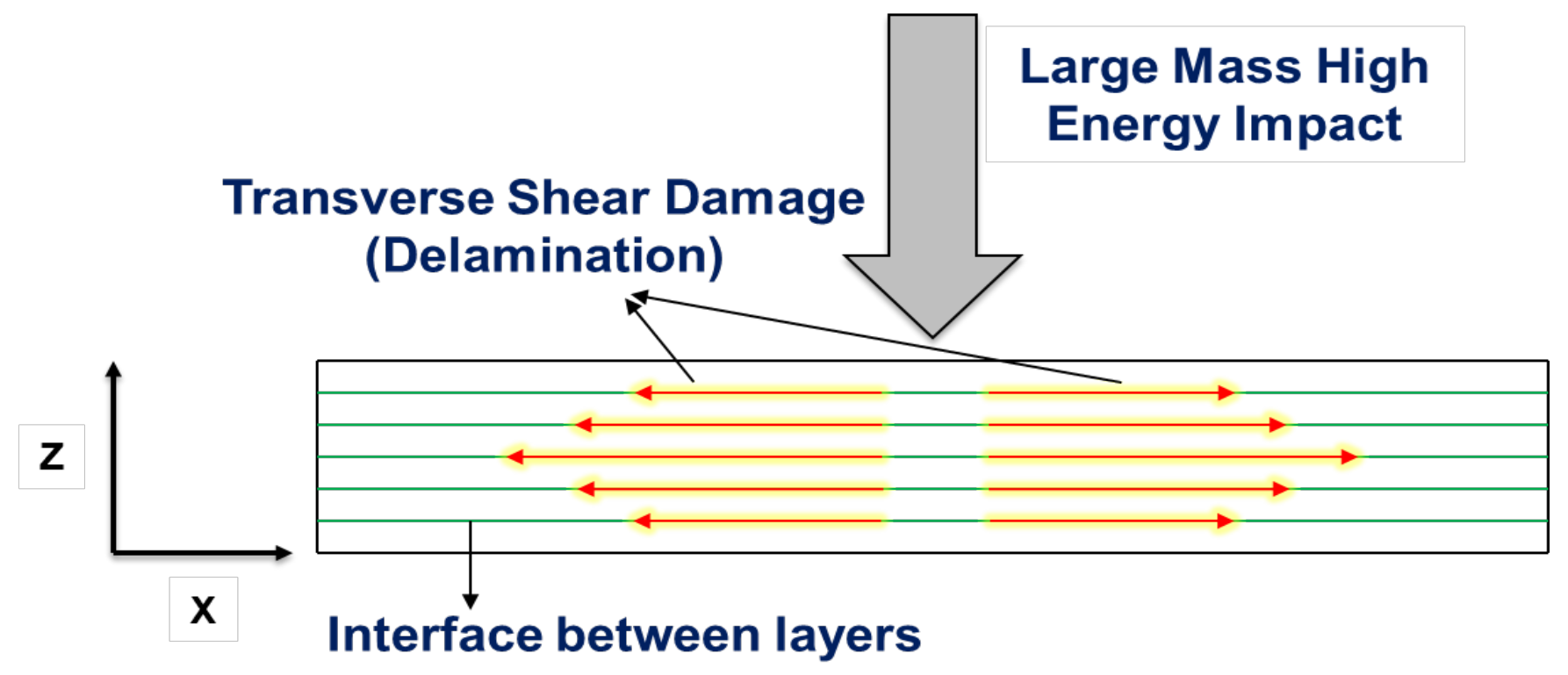
MEDE Objective Function-2
(Materials in Extreme Dynamic Environments)

Improve delamination resistance **(durability)** and stiffness-retention **(damage tolerance)** in plain-weave (PW) S-2 glass epoxy thick section composites under high energy impacts.

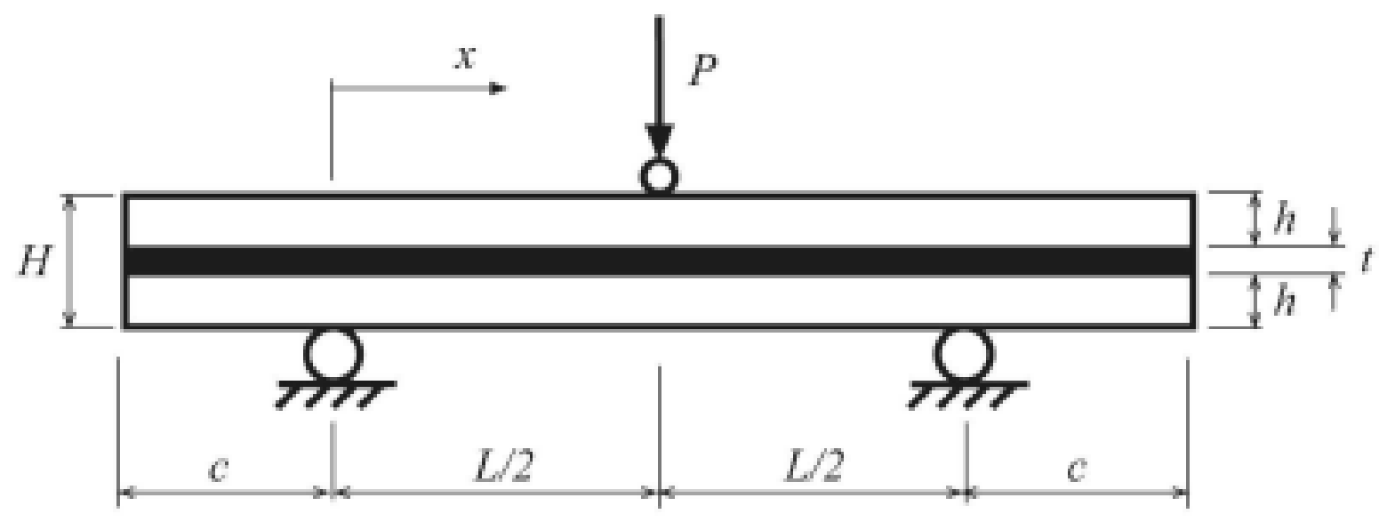
Delamination- Main failure mechanism in high energy low velocity impacts (LVI) and causes a significant reduction in stiffness (limiting life after hit).



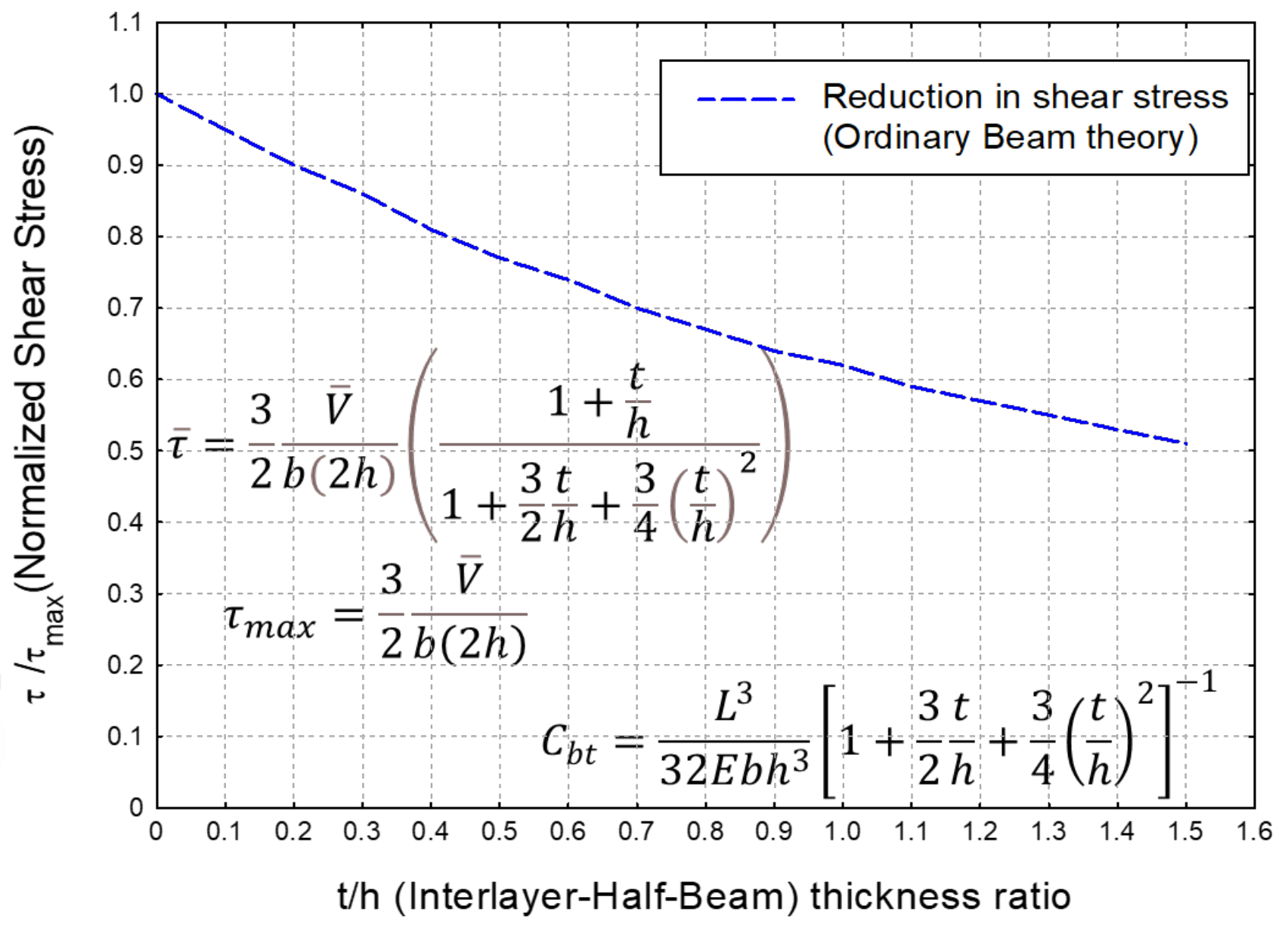
Interlayer toughening : Thin and compliant interlayers (thermoplastic polyurethane films) selectively placed through the thickness improves delamination resistance and thus, helps in retention of stiffness.

Background & Motivation

The **Alfredsson-Gillespie** analytical solution (2008) showed that a thin and compliant interlayer decouples the section, disrupting the shear stress-strain profile in the layered beam under fle



Reduction in transverse shear stress $\frac{\tau}{\tau_{max}}$ was also shown using the ordinary beam theory (Gere, Timoshenko, 1984) although it predicted a decrease in compliance (C_{bt})



Reducing Interlaminar Shear Stress

The interlayer reduces transverse shear stress **(decoupling)** and deflects crack growth in Mode-II **(mitigating the propagation of delamination)**.

Enhancement of shear strength under transverse compression: 'A phenomenological Mohr–Coulomb failure criterion for composite laminates under interlaminar shear and compression' (Xiao, Gillespie, 2007).

$$\left(\frac{\sigma_{3T}}{S_{3T}}\right)^2 + \left(\frac{\tau_{23}}{S_{230}+S_{SRC}}\right)^2 + \left(\frac{\tau_{31}}{S_{130}+S_{SRC}}\right)^2 + \left(\frac{\left\langle\left(\frac{\sigma_{3c}}{S_{3c}}\right)-\beta\right\rangle}{1-\beta}\right)^2 = 1$$

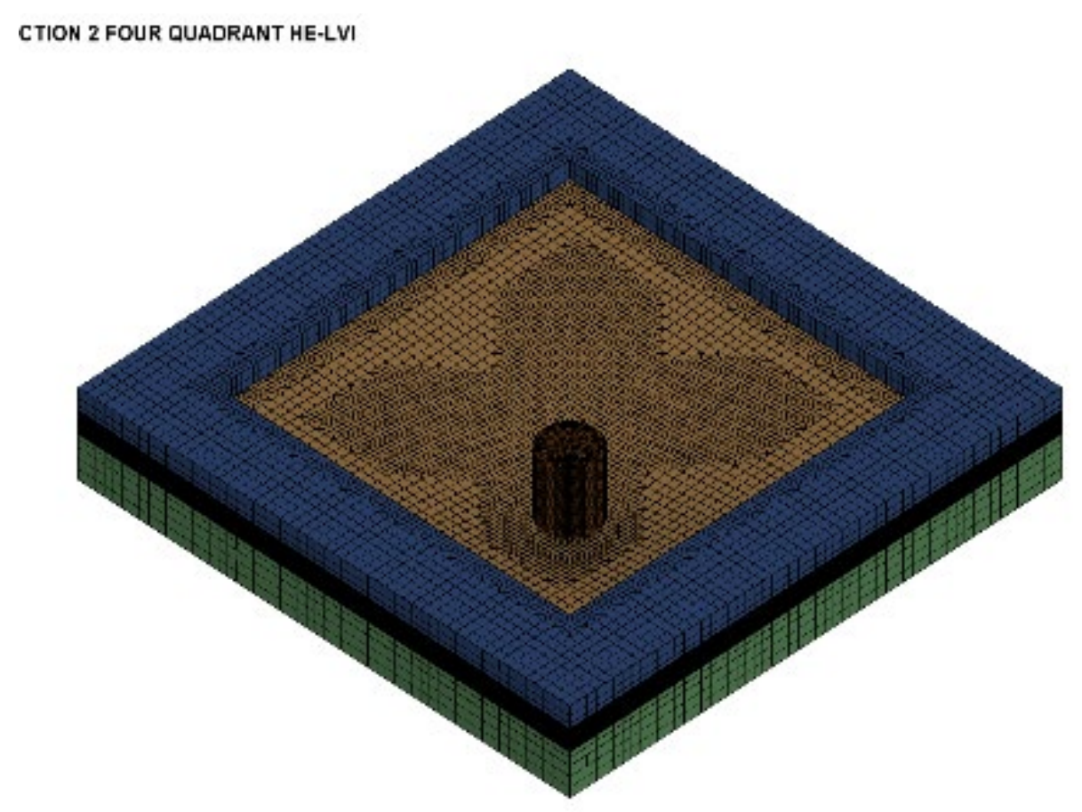
$$S_{SRC} = \sigma_{3c}Tan(\varphi) \qquad Tan(\varphi) = f_o\left\{1-\alpha\left(\frac{\sigma_{3c}}{S_{3c}}\right)\right\}$$

Strain rate enhancement of shear strength: Quasi-static shear strength S_{23}, S_{31}(58 MPa) appreciates at strain rates in these dynamic impacts.

Predictive Modeling
(MAT162, LS-Dyna)

Baseline panel (44 layers of 24oz/yd^2 PW 5x5 S-2 glass/SC-15 epoxy matrix).

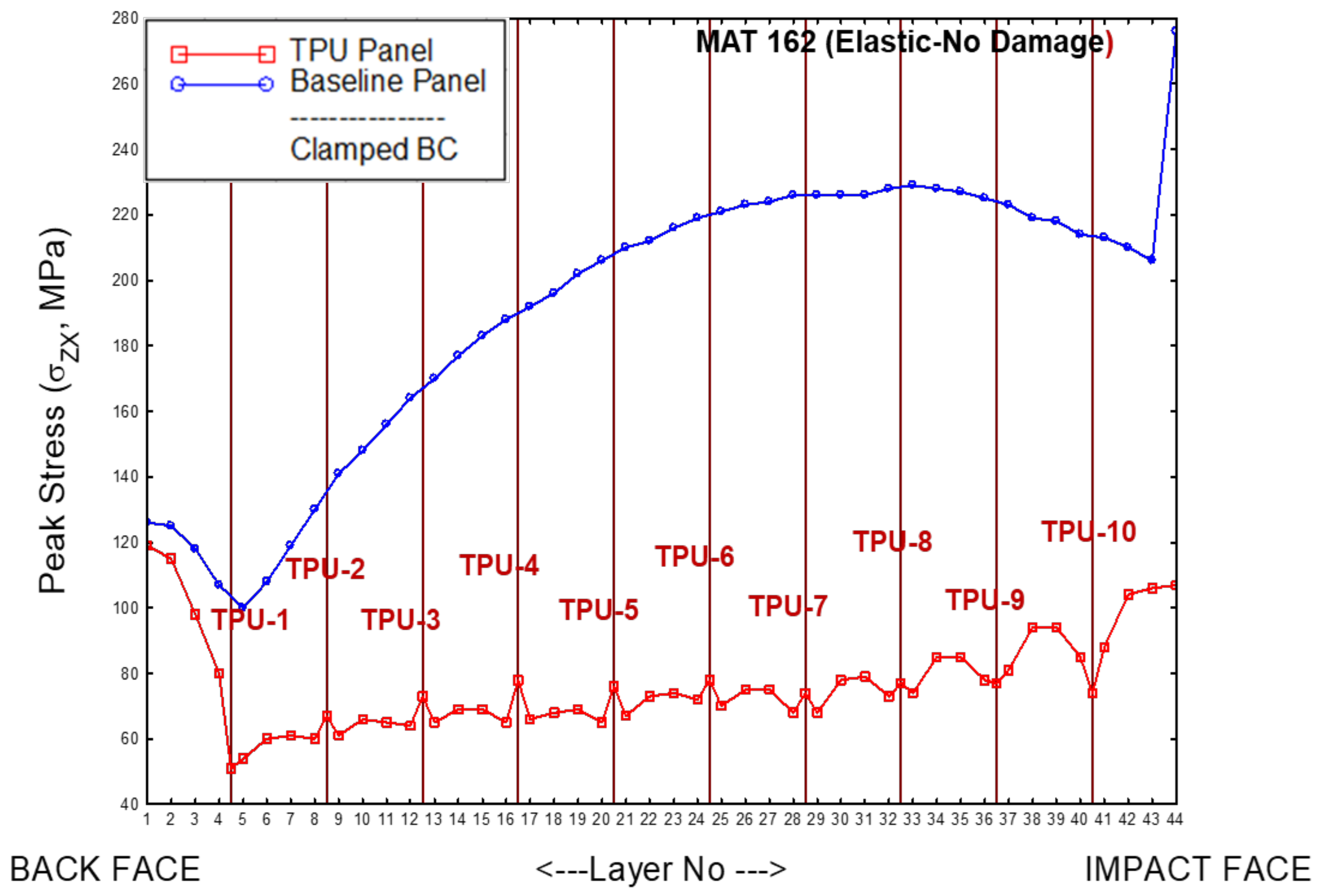
Interlayer (TPU) panel (44 layers of 24oz/yd^2 PW 5x5 S-2 glass/SC-15 epoxy matrix with ten (10) Thermoplastic Polyurethane (TPU) [UAF-472] Interlayers.



TPU modeled as bilinear elastic-plastic (MAT003) with initial modulus of 245 MPa, plastic modulus of 6.9 MPa, yield strain of 3.7% (*Boyd et al., 2018*)

- Panel Dim: 711.2 mm x 711.2 mm and 28-32 mm thick.
- FEM: 44 layers with 3 elements through thickness per layer.
- Material Model: MAT162 for S-2 glass/SC-15 epoxy matrix
- TPU behavior: Non-linear, large deformation/high shear strain and rate dependent.
- Impact Energy : 7.6 kJ

Predictions: Transverse Shear Stress



Reduction in peak transverse shear (σ_{ZX}, σ_{YZ}) stresses (57 % on average) between the Baseline and TPU panels.

Drop Experiments:
High Energy Low Velocity Impact

- Four (4) dynamic impacts (7.4 kJ) i.e., two repeated impacts/ panel at the center.
- Drop Tower with catch-mechanism to record rebound height.

$$E_{Absorbed} = \frac{1}{2}m_p\left(V_I^2 - V_R^2\right)$$

Through-transmission ultrasound scanning (C-Scans) was done before and after each impact to track the spread of delamination.

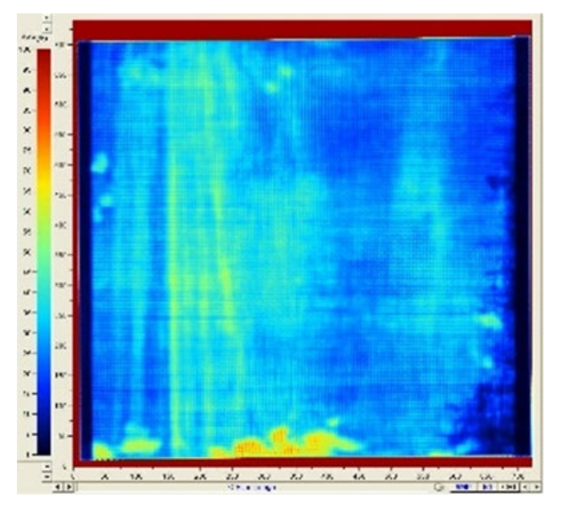
Stereo Digital Image Correlation (DIC) used to measure back face deflections and strains.

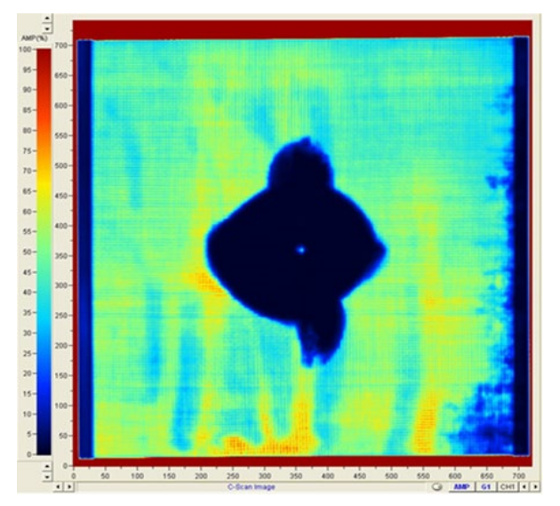
Stiffness(K) **retention** of the panels is determined from the dynamic load-deflection curves of the first & second impact.

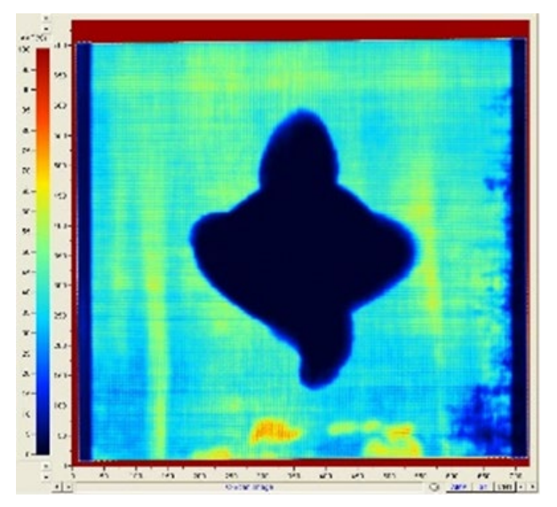
$$\left\{\frac{K_{Second\ Impact}}{K_{First\ impact}}\right\}_{Baseline} < \left\{\frac{K_{Second\ Impact}}{K_{First\ impact}}\right\}_{TPU}$$

Results

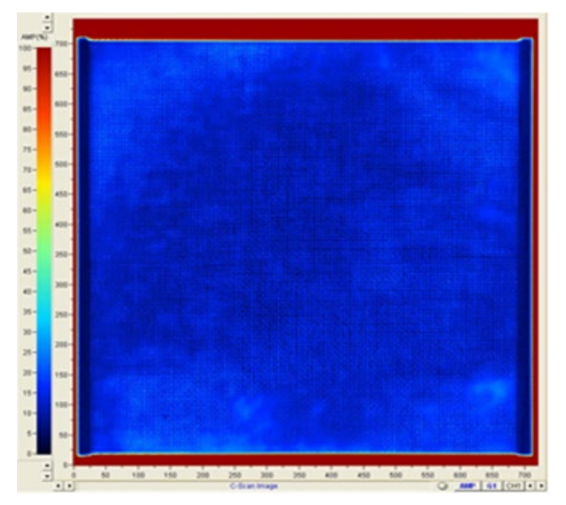
Transverse shear- interlaminar failure (delamination) is significant in Baseline panel.

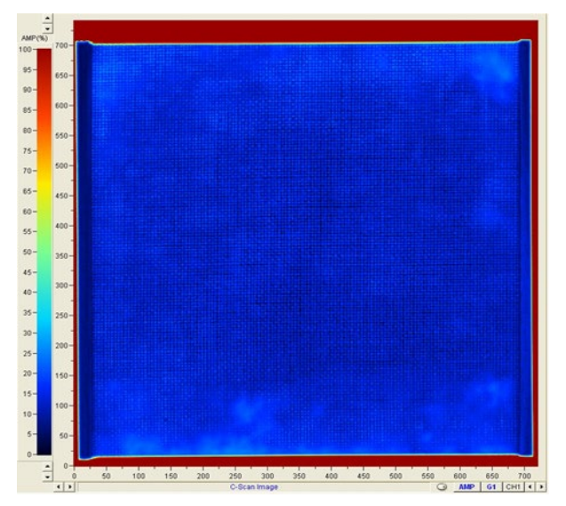

Before Impact

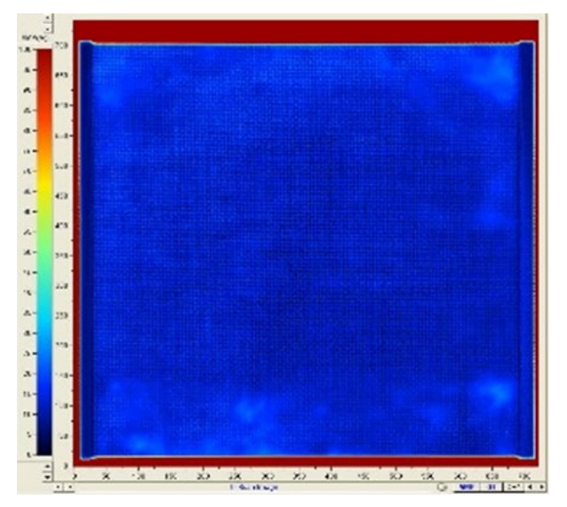

First Impact


Second Impact

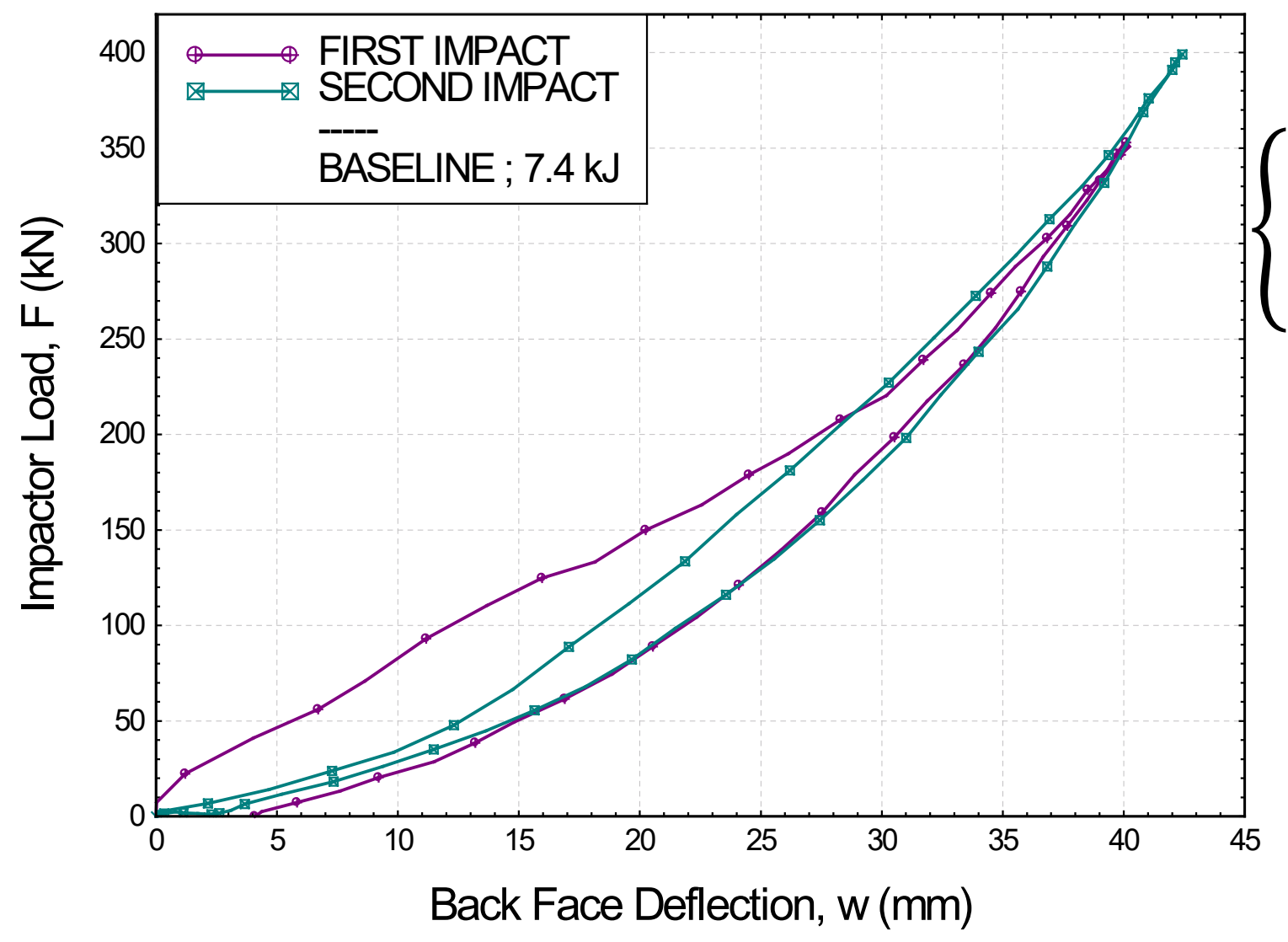
Panel with TPU interlayers shows **no delamination** after both impacts.


Before Impact


First Impact


Second Impact

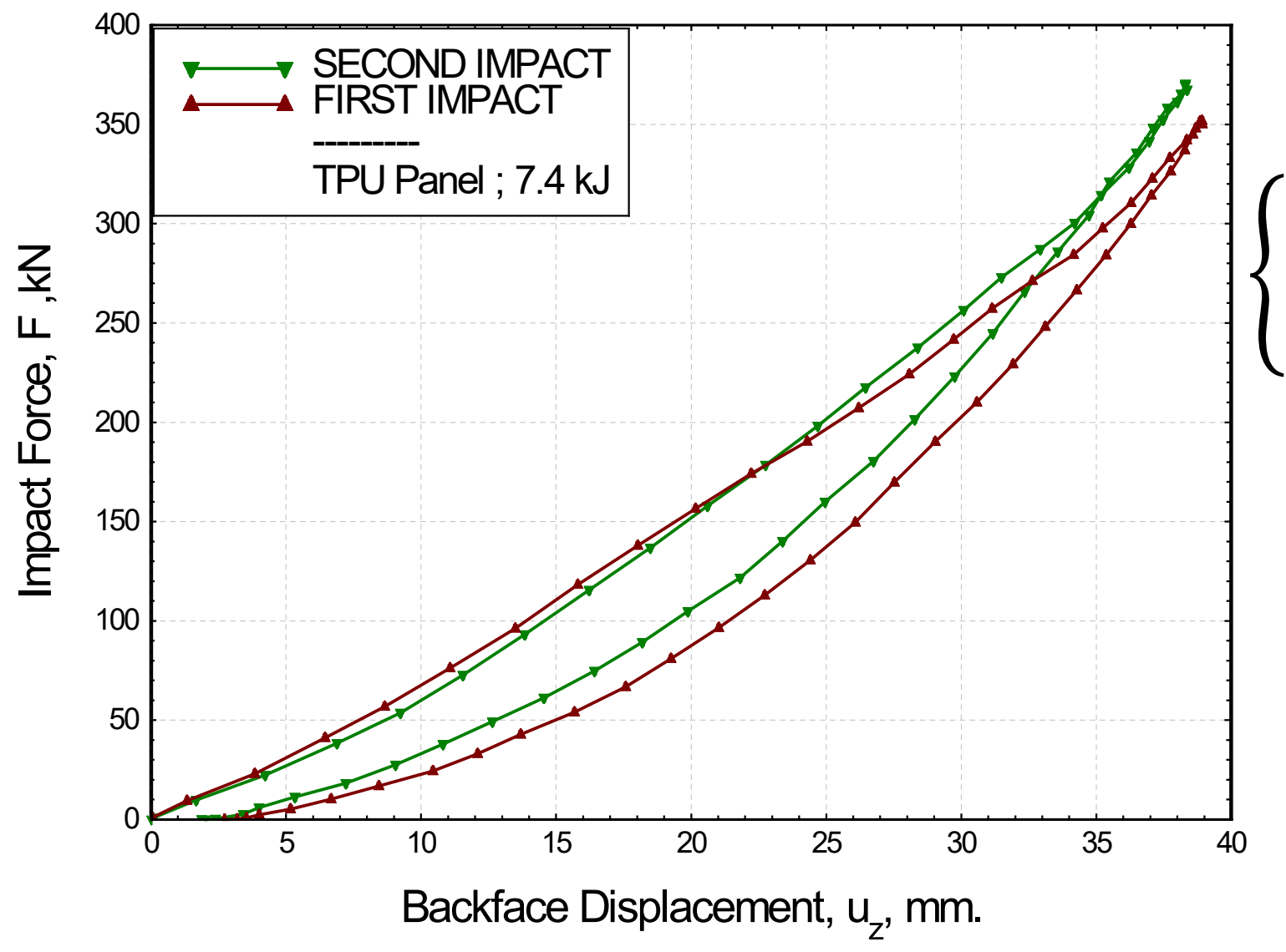
Delamination influenced dynamic stiffness(K) loss in the Baseline panel is significant. Stiffness retention at 44%.



$$\left\{\frac{K_{Second\ Impact}}{K_{First\ impact}}\right\}_{Baseline}$$

44%

Panel with TPU interlayers shows very good (91%) retention of stiffness (K)



$$\left\{\frac{K_{Second\ Impact}}{K_{First\ impact}}\right\}_{TPU}$$

91%

Acknowledgements

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