PENETRATION MECHANICS OF SOFT LAMINATES AND FABRICS

K. Ayotte (BME), B. Gama, R. Adkinson (ARL)

University of Delaware . Center for Composite Materials

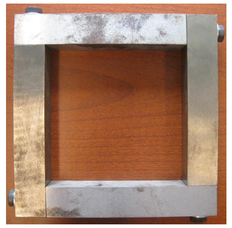
MOTIVATION AND OBJECTIVES

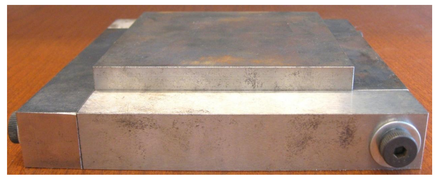
- Penetration mechanics of soft laminates are not well understood, in fact, there is an insignificant amount of literature available on this subject.
- Penetration mechanics of thick-section composites have been recently developed following a Quasi-Static Punch Shear Test (QS-PST) experimental methodology.
- The main objective of this research is to use QS-PST methodology to understand the non-linear penetration damage mechanisms of soft laminates.
- Other objectives include (i) Development of new test methods, & (ii) Development of new penetration models for this group of materials.

APPROACH

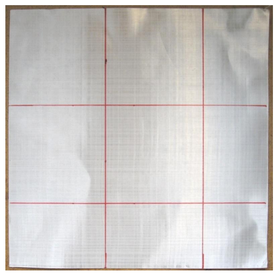
- Processing of soft laminates
- Quasi-static penetration testing
  - Different thickness
  - Different support spans
- Damage evaluation
- Analysis of experimental data

PROCESSING OF SOFT LAMINATES



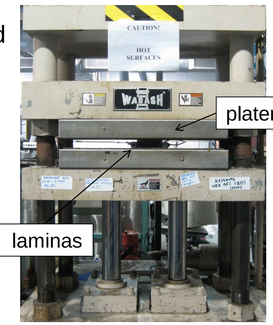


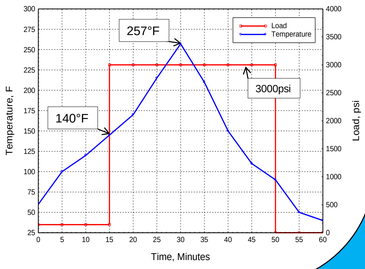
- 12”x12” soft lamina sheets are cut to smaller dimensions.
- All laminas are kept in the same orientation.
- Compression molding on a hot press is used for processing
- Soft laminas are sandwiched between two molding plates.
- High temperature films are set between laminas and molding plates.
- Top molding plate is 1”, bottom molding plate is 0.25” thick.



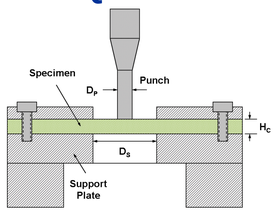
COMPRESSION MOLDING ON A HOT PRESS

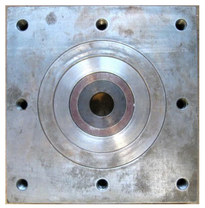
- Bolts on frame are tightened around molding plates and frame is placed in the center of hot press platens.
- Platens are heated to 150°F and the load is set to 145psi.
- Once core temperature of laminas reach 140°F, load is increased to 3000psi and platen temperature to 267°F.
- Pressure is maintained until core temperature reaches 257°F. (Max. allowed core temp. is 267°F).
- Laminate is cooled when core temperature reaches 257°F.
- Laminate is unloaded when core temp. reaches below 140°F.





QS-PST METHODOLOGY



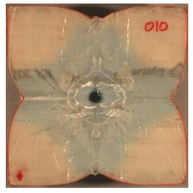


- Proven capable of quantifying ballistic damage mechanisms and energy dissipation in thick-section composites.
- Specimens are tested at different support span diameter (D_s) to a constant punch diameter (D_p) ratios (SPR = (D_s / D_p).
- The resulting load-displacement data for each test can be used to calculate the energy absorption by different energy absorbing damage mechanisms.

QS PENETRATION DAMAGE MECHANISMS

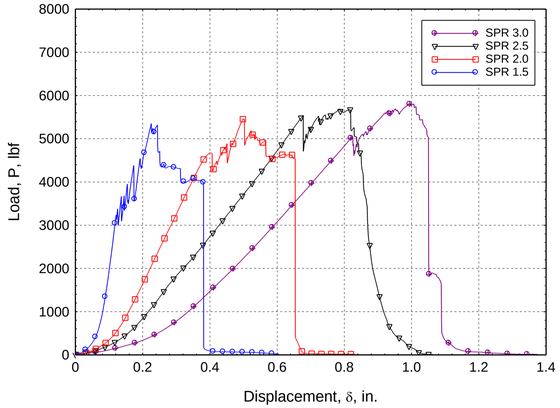
SPR = 1.5

More fiber pull out and more shear deformation is observed with increasing SPRs.



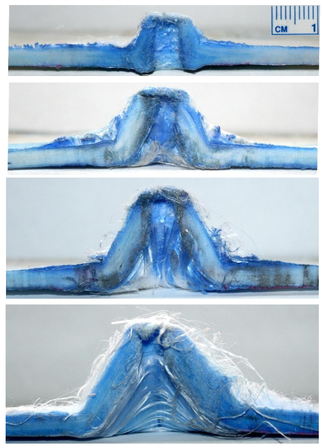
SPR = 3.0

QS PENETRATION FORCE - DISPLACEMENT



Inelastic deformation prior to first failure is associated with the formation of the inelastic shear cone

DAMAGE MECHANISMS AT DIFFERENT SPRs



SPR = 1.5

SPR = 2.0

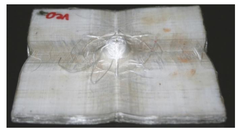
SPR = 2.5

SPR = 3.0

PENETRATION MECHANICS OF SOFT LAMINATES AND FABRICS
(Continued)

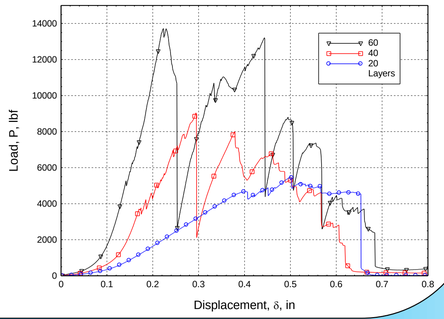
DAMAGE MECHANISMS – EFFECT OF LAMINATE THICKNESS


20 Layers


40 Layers


60 Layers

♦ Effects of SPR start to diminish as the number of layers of lamina increase.
♦ More peaks and valleys are seen in thicker laminates.

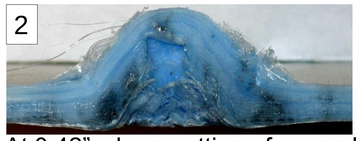


DAMAGE MECHANISMS AT DIFFERENT DISPLACEMENTS

1

At 0.40” displacement, all fibers remain intact.

2

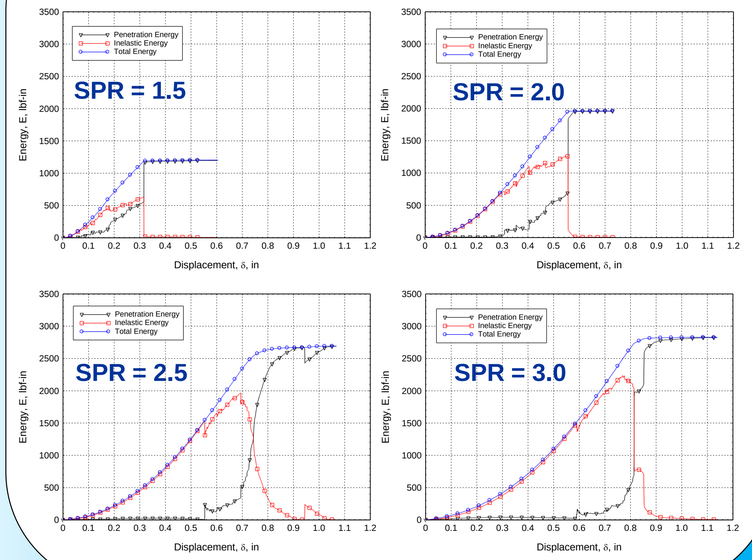


At 0.42”, shear cutting of a couple layers of fiber is observed.

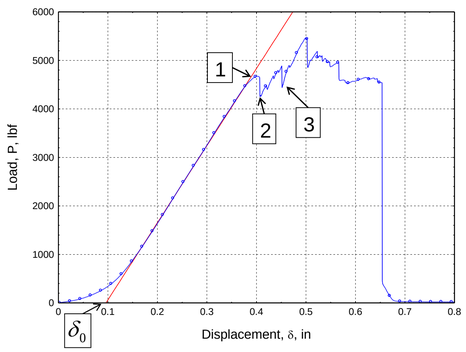
3

At 0.46”, shear cutting through half of layers.

QUASI-STATIC ENERGY DISSIPATION



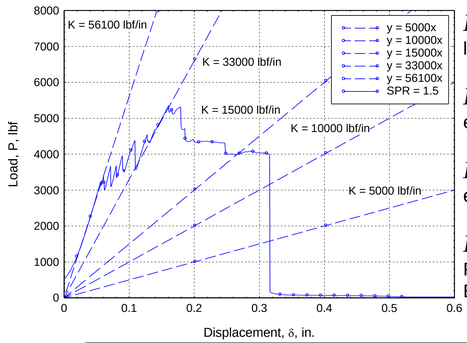
DAMAGE MECHANISMS AT DIFFERENT DISPLACEMENTS



♦ **1** – The “knee” before the first local peak
♦ **2** – After first failure
♦ **3** – After second failure

♦ A load stop test is used to investigate damage as a function of displacement.
♦ The test is stopped at different displacement levels signifying different damage mechanisms.

QUASI-STATIC ENERGY DISSIPATION



K – Stiffness, lbf/in.

E_{IE} – Inelastic energy, lbf-in.

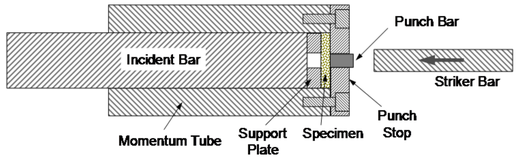
E_T – Total energy, lbf-in.

E_{PE} – Penetration Energy, lbf-in.

$$K = \frac{P}{\delta'} \qquad \delta' = \delta - \delta_0 \qquad E_T = \int P d\delta'$$

$$E_{IE} = P^2 / 2K \qquad E_{PE} = E_T - E_{IE}$$

NEW TEST METHODOLOGIES



Direct Impact Punch Shear Test (DI-PST)

♦ The direct impact punch shear test (DI-PST) will be used to investigate failure mechanisms under high strain rates.
♦ The dominant transverse punch shear damage mechanisms of hard composites are almost absent in quasi-static punch shear tests, so DI-PST will be used.
♦ A striker bar is shot out of a pressurized tank at high velocity and strikes the punch through the specimen.
♦ Waves transmit through the incident bar and resulting data from a strain gage is used to determine dynamic compression force-displacement behavior of different materials

SUMMARY

♦ Soft Laminates are manufactured on a hot press using compression molding.
♦ QS-PST’s are used to produce load displacement data which is used to investigate energy dissipation and penetration damage mechanisms.
♦ Larger SPRs are associated with greater shear damage and more fiber pull out.
♦ Thicker soft laminates alter the effects of SPR.
♦ Larger SPRs result in greater dissipation of energy and greater penetration energy.

ACKNOWLEDGEMENTS

Funding for this work is provided by ARL-CMR MIPR (Soft Laminate).