UNUSUAL TRANSVERSE COMPRESSION RESPONSE OF NON-WOVEN BALLISTIC LAMINATES

Brian Scott PhD, PE
Major, Ordnance, USAR (ret)
US Army Research Laboratory
APG, Md 21005

TECHNOLOGY DRIVEN. WARFIGHTER FOCUSED.

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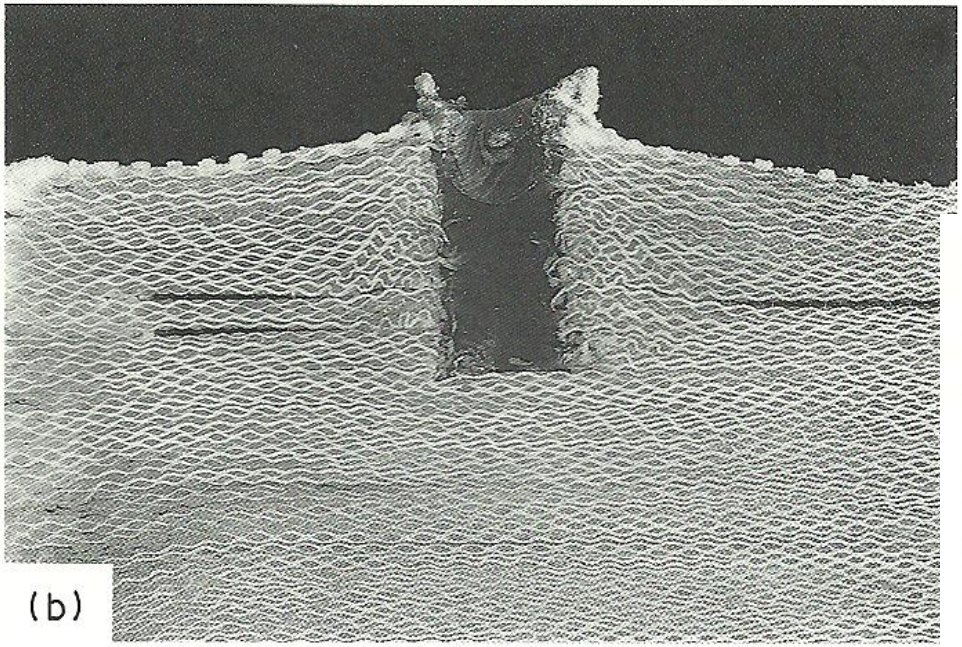
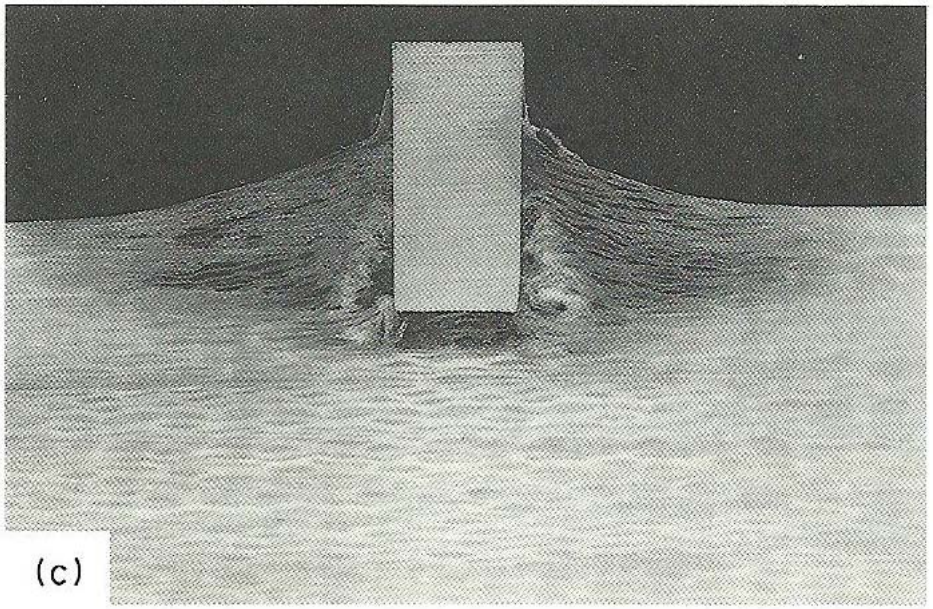
Outline

- Reasons for compression testing
- Transverse constrained compression testing
- Unusual response of unidirectional laminates “unis”
- Implications on the mechanics of penetration

Penetration Cavities Measured by Woodward, et al.



Woven Kevlar @ 336 m/s



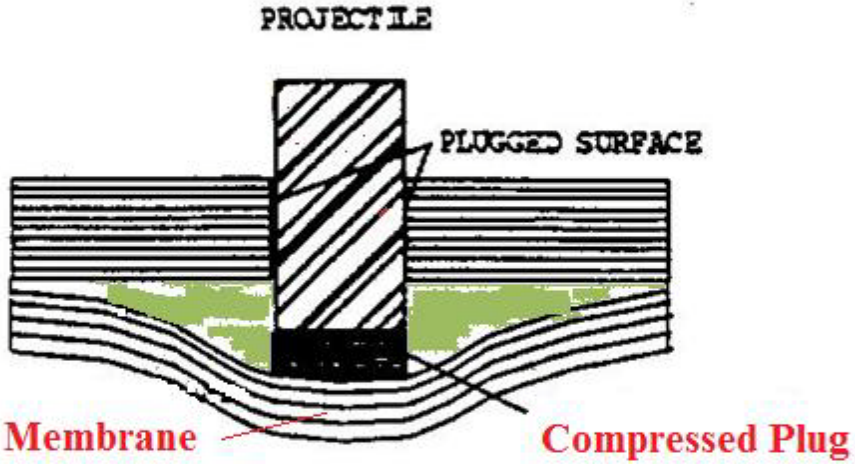
Woven GRP @ 330 m/s

Woodward, R.L, Egglestone, G.T, Baxter, B.J, and Challis, K, "Resistance to Penetration of Fibre-Reinforced Composite Materials", Composites Engineering, Vol 4, No.3, pp 329, 1994.

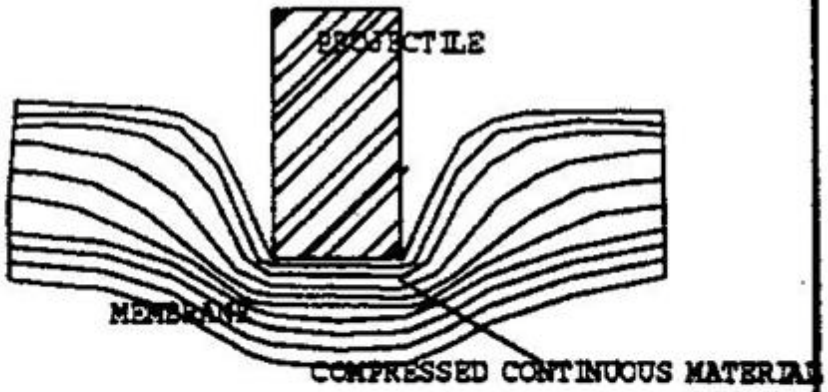
Assumed Simplified Behavior

CROSS PLIED UNIDIRECTIONAL LAMINATES

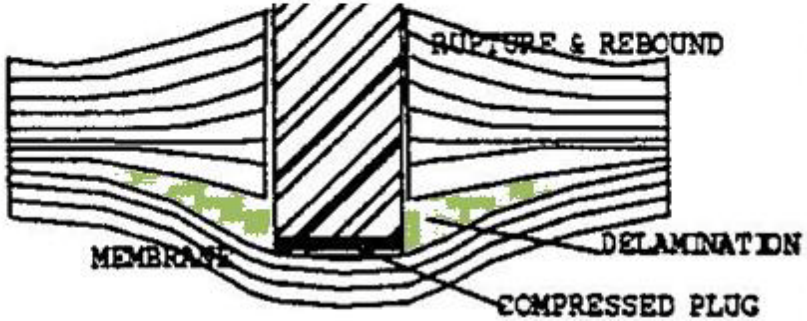
WOVEN OR STRUCTURAL LAMINATES



Classic Plug and Membrane

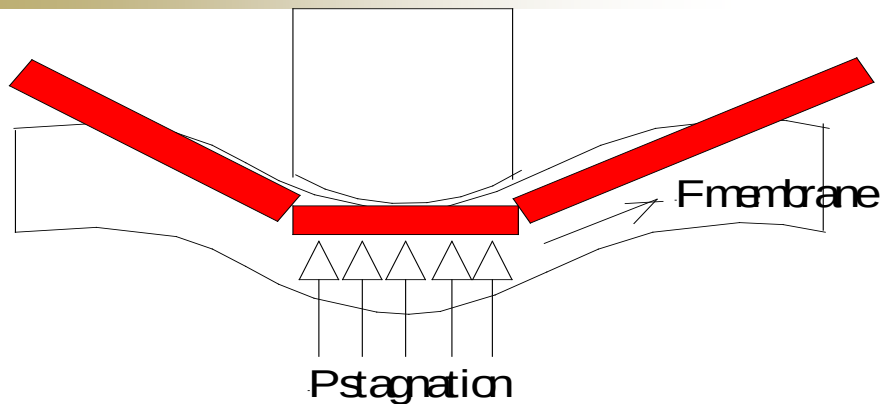


Stage I Prior to front layer rupture



Stage II Post front layers rupture

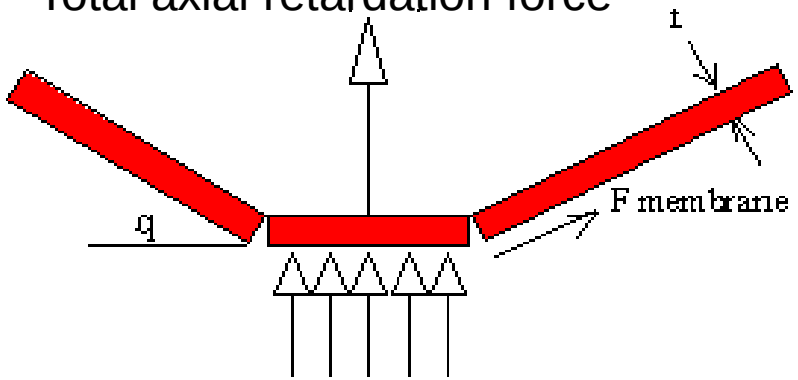
Predominant Deceleration Forces



Assume : the absence of localized shear

Post phase I deceleration

Total axial retardation force



Z compression stress + stagnation P

Woodward's analytic model in two stages: phase I : momentum transfer with plug compression and static resistance

phase II: membrane energy capacity

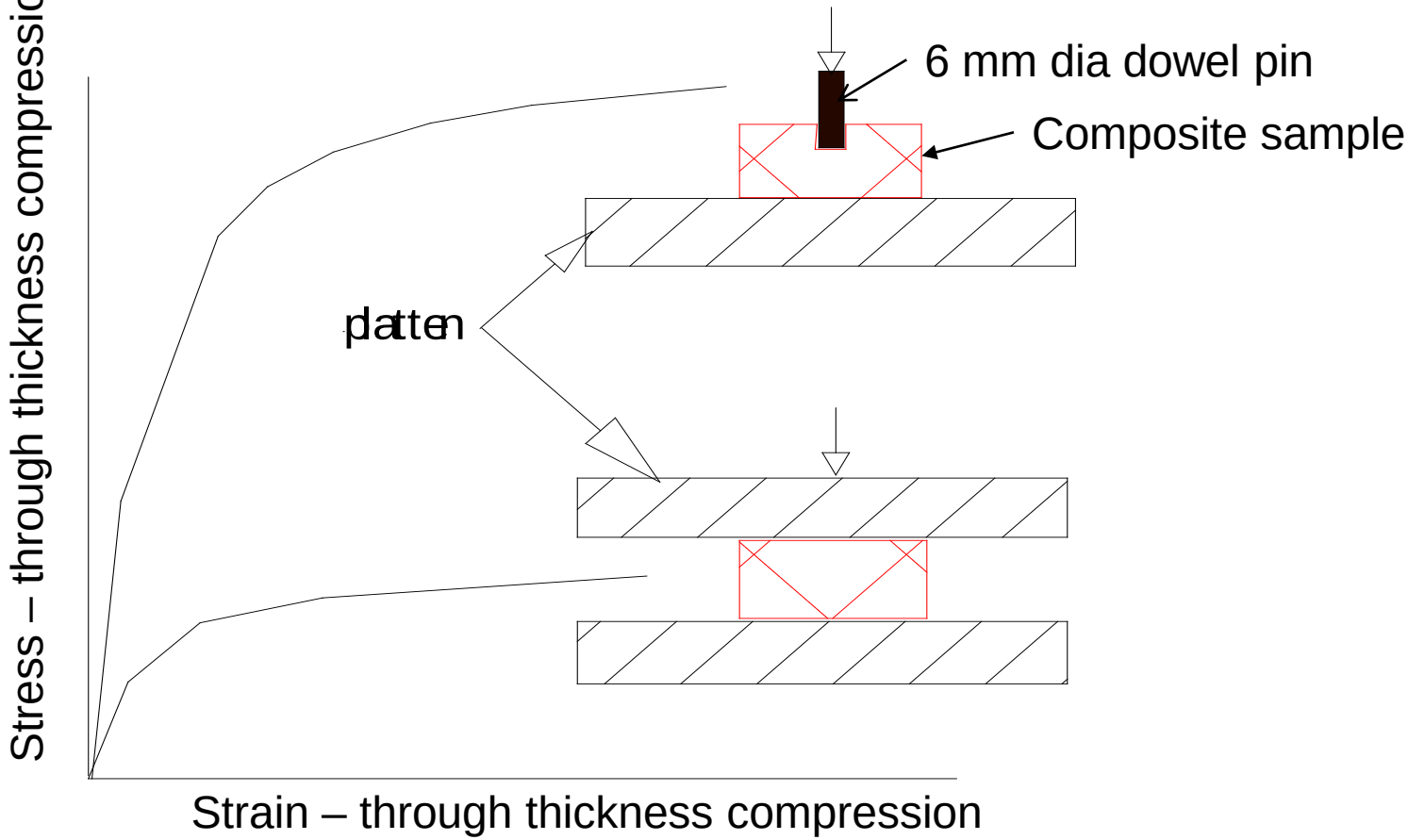
NEED THE STATIC AXIAL RESISTANCE FORCE

Woodward, R. L. and I. G. Crouch, "A Computational Model of the Perforation of Multi-Layer Metallic Laminates," MRL-RR-9-89, Materials Research Lab, DSTO, Australia, 1989.

Measurement of Static Axial Resistance Force

Constrained Compression Test

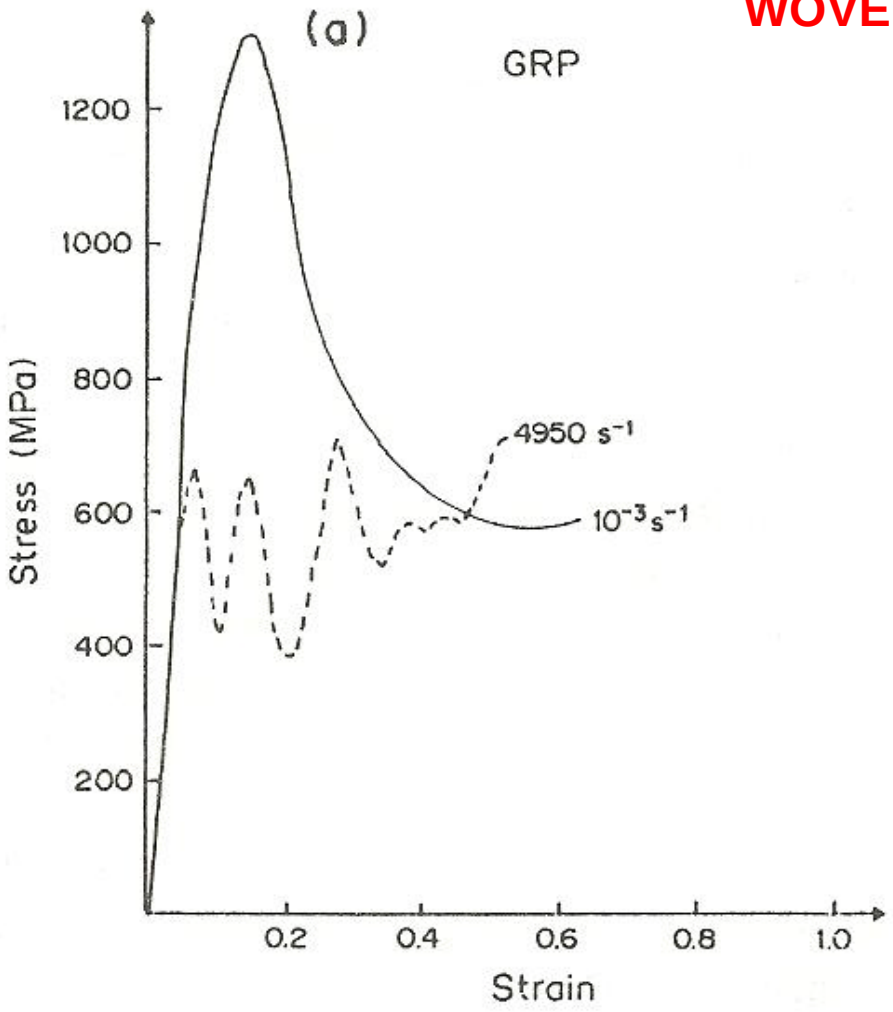
Composites Engineering, Vol 4, No. 3, Woodward, et al, 1994

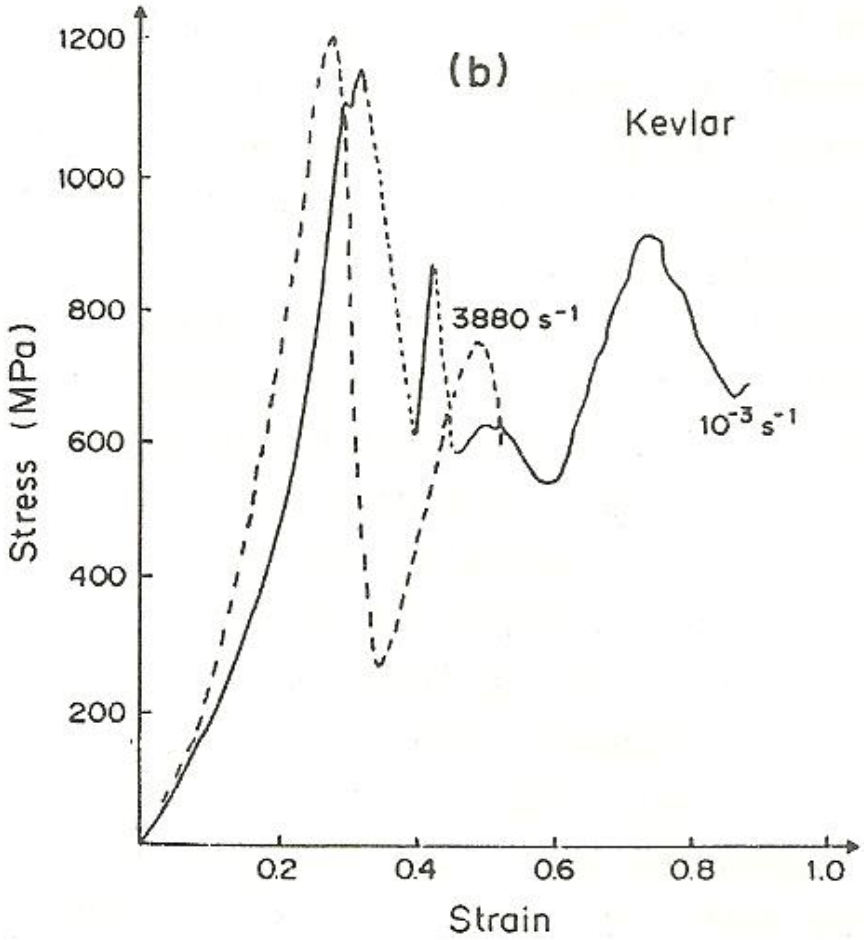


Woodward's Observations

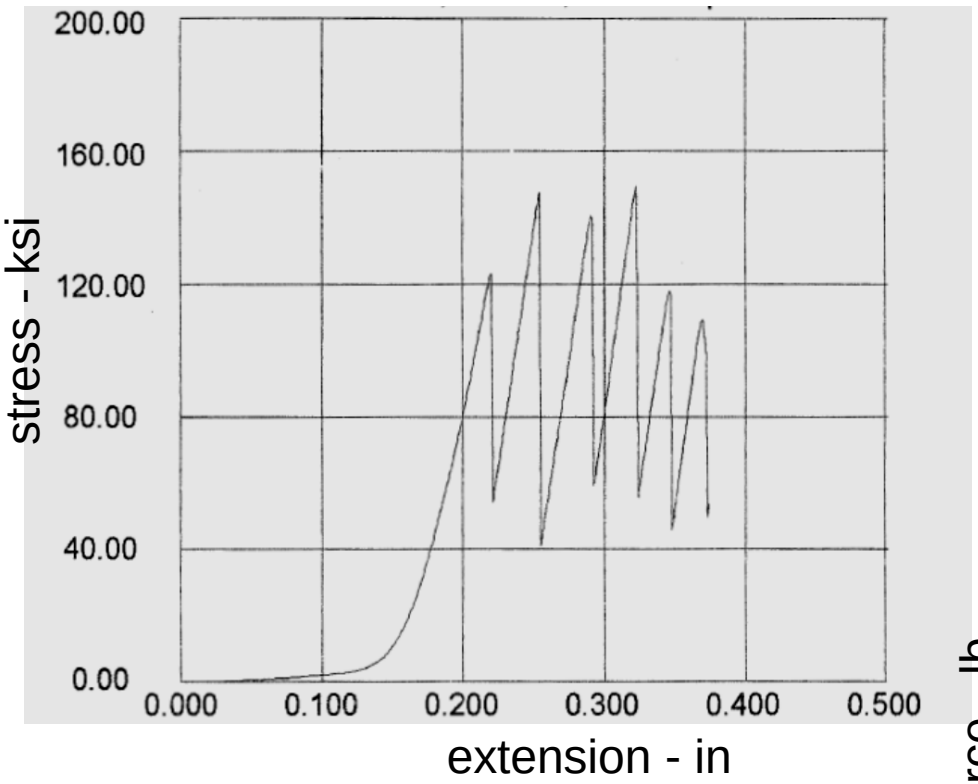
Woodward, R.L, Egglestone, G.T, Baxter, B.J, and Challis, K, "Resistance to Penetration of Fibre-Reinforced Composite Materials", Composites Engineering, Vol 4, No.3, pp 329, 1994.

WOVEN REINFORCEMENT



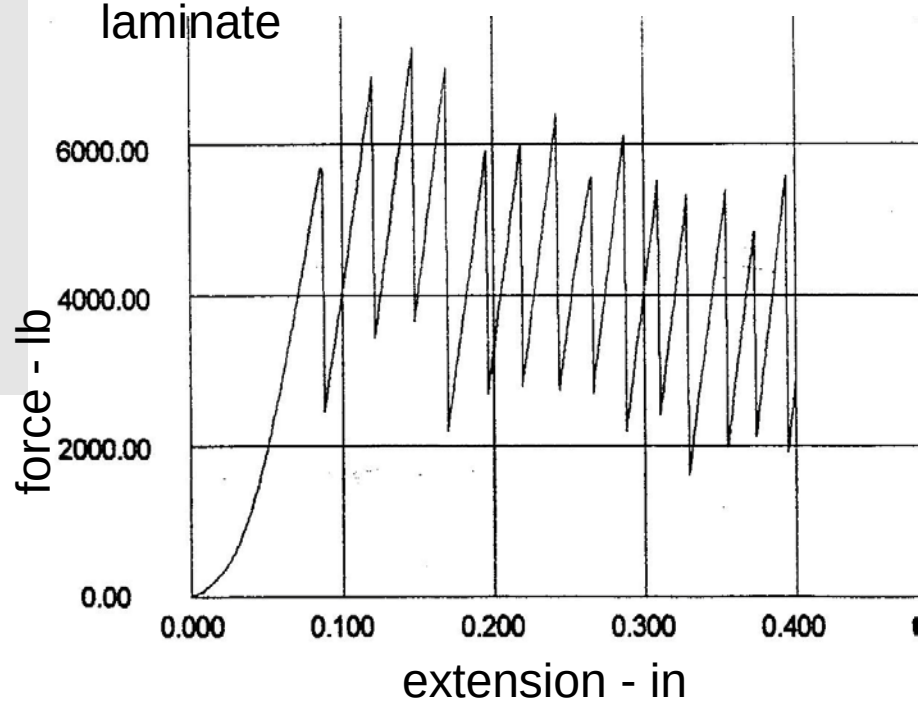


OBSERVED RESPONSE WITH UNIDIRECTIONAL LAMINATES



Quasi-static, constrained compression, Aramid fiber, polyolefin unidirectional laminate

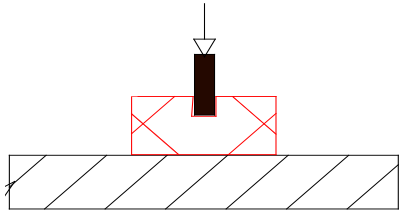
Quasi-static, constrained compression, UHMWPE fiber, polyolefin unidirectional laminate



CYCLIC RESPONSE !
(both aramid and uhmwpe)

Material Matrix For Repeat Constrained Compression Testing

Material	Dimensions (Length, Width, Thickness)	Mold Pressure (psi)	Process Temp (°F)	Areal Density (lb/ft^2)
S2-HJ1 (MIL-DTL-64154, Class A)	6.00,6.00,~1.0			10.0
KRP (MIL-DTL-62474, Class D)	6.00,6.00,~1.0	250	291	7.3
Honeywell Spectra Shield II SR-3124	6.00,6.00,~1.0	819	257	5.04
Honeywell Spectra Shield II SR-3124	6.00,6.00,1.0	2833	258	5.04
Dyneema HB-26	6.00,6.00,1.0	805	258	5.08
Dyneema HB-26	6.00,6.00,1.0	712	258	5.09
Honeywell Spectra Shield II SR-3124	6.00,6.00,1.0	2708	275	5.0
Dyneema HB-26	6.00,6.00,1.0	2708	277.6	5.0
TBA (Thermo Ballistic A)	6.00,6.00,-.--			

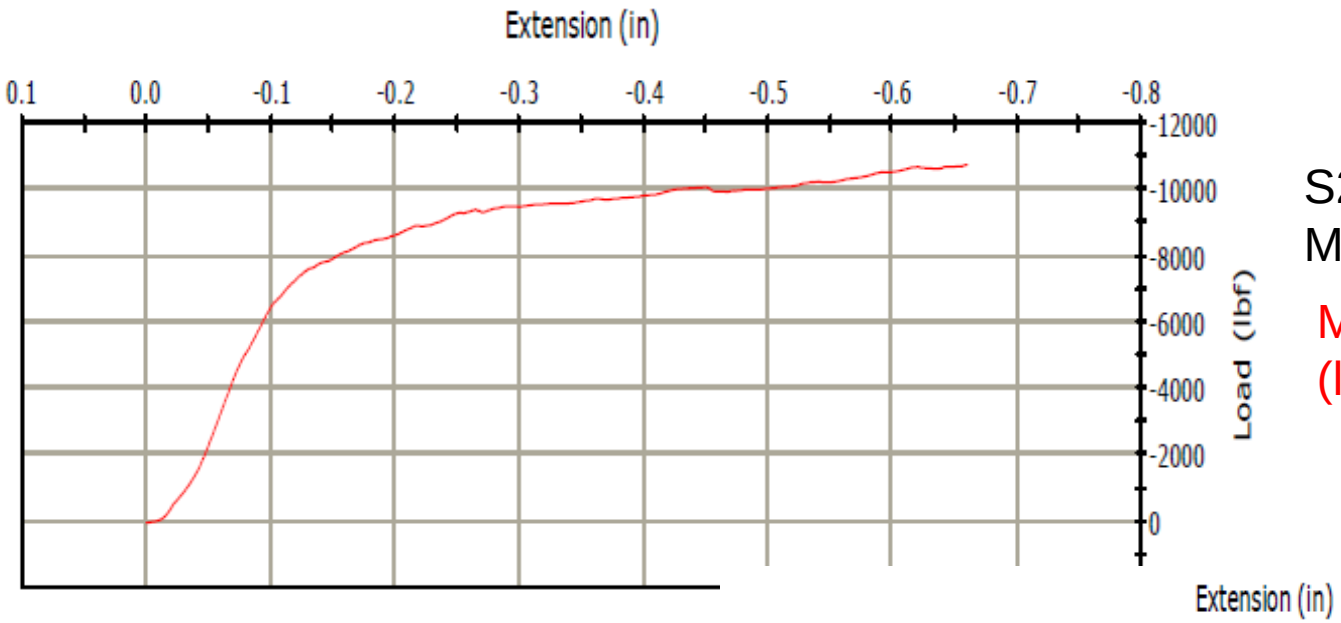


Woven and uni

High & low pressure

High & low peak temperature

Woven Laminates

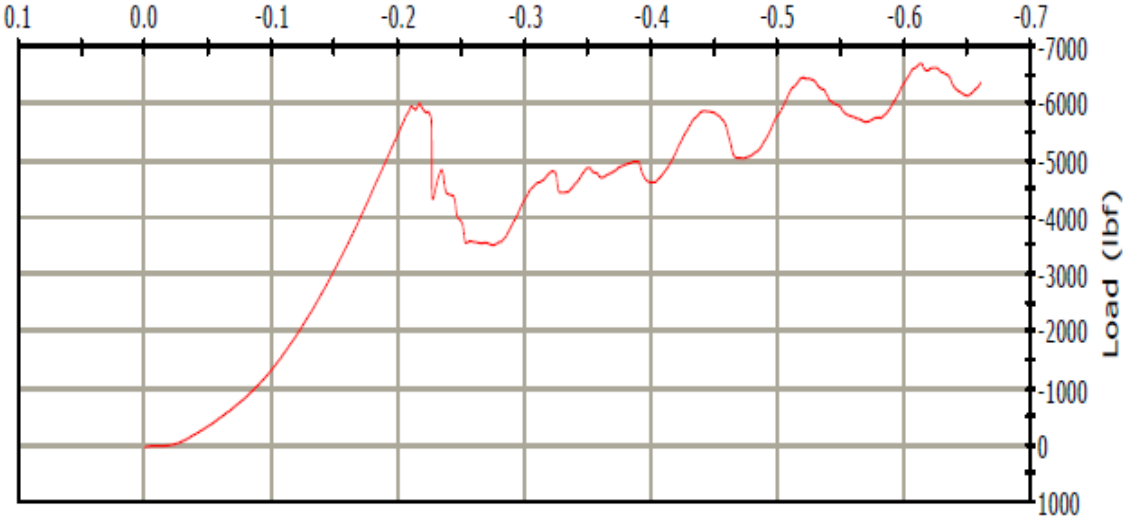


S2/phenolic, woven
MIL DTL 64154B class A

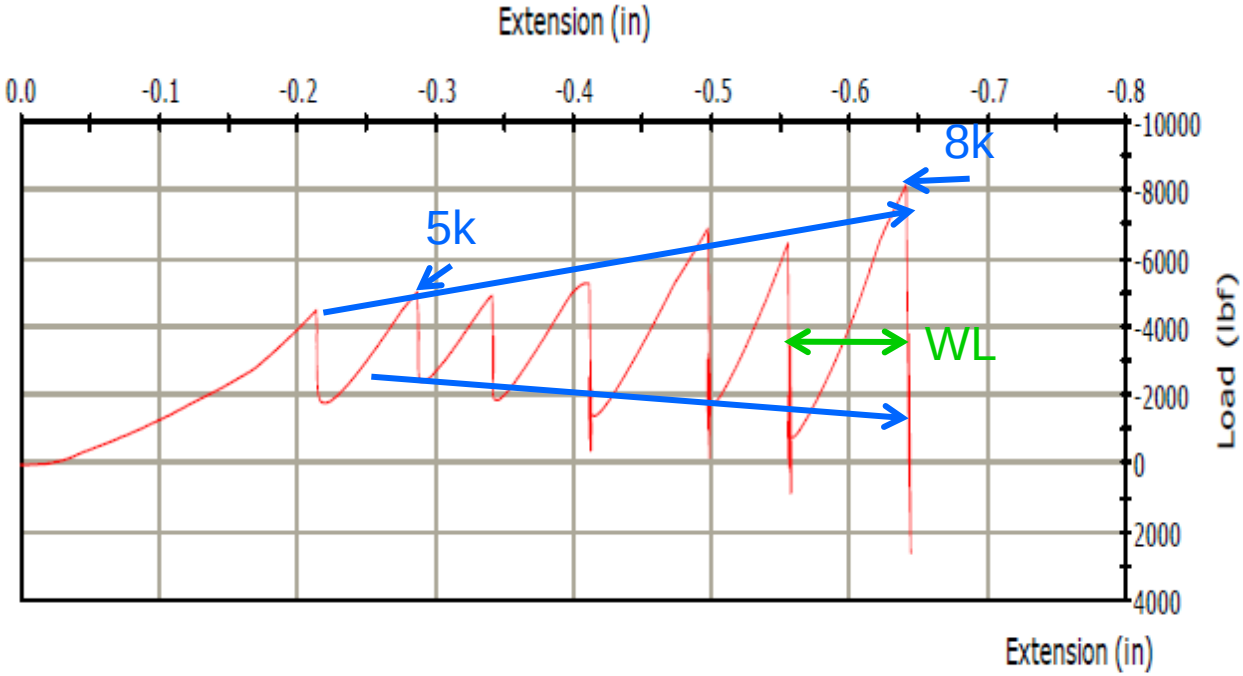
Monotonic response
(large static strength)

Kevlar/phenolic, woven
MIL DTL 62474F class D

Moderate cycling + increasing average

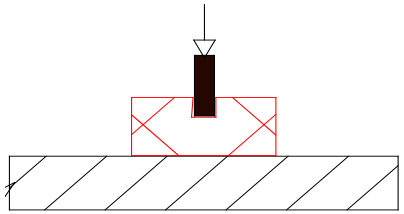


Constrained Compression SSII at Two Consolidation Pressures

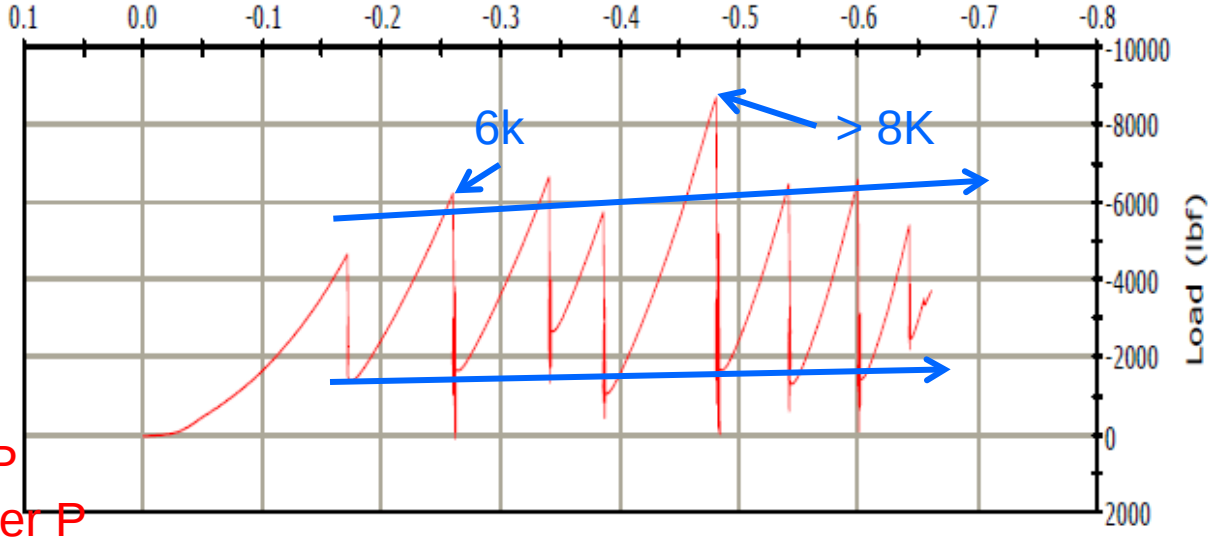


Spectrashield II, uni
Pressed @ 800 psi

WL= number of plies ruptured per cycle

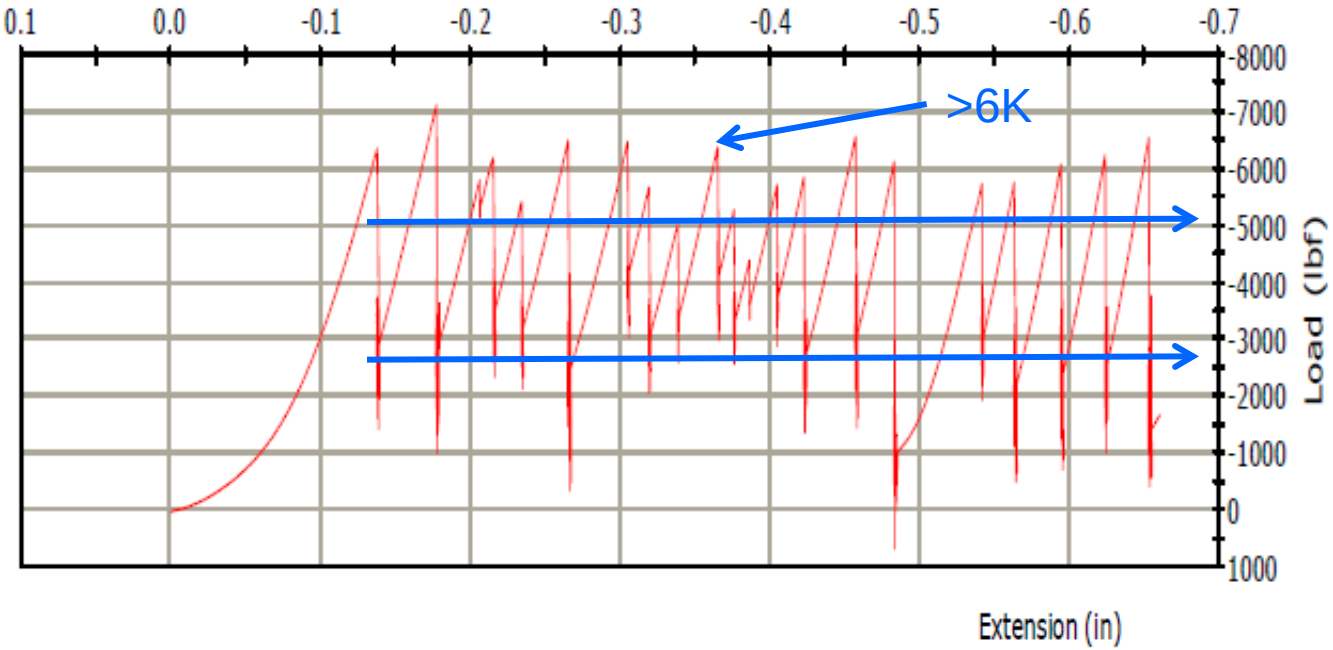


Spectrashield II, uni
Pressed @ 2800 psi



Flatter response at high P
Strength higher with higher P

Constrained Compression HB26 at Two Consolidation Pressures



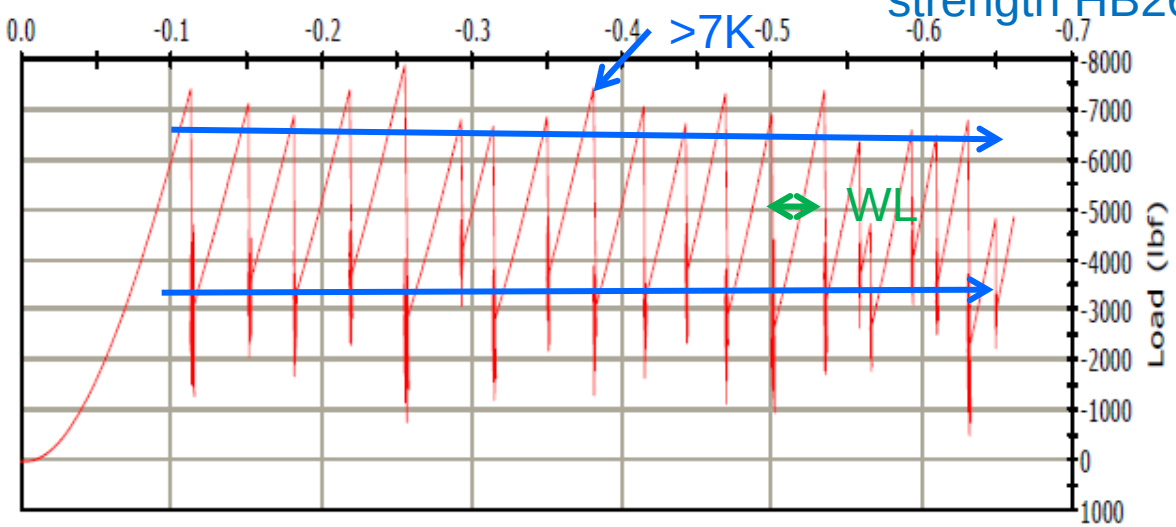
Dyneema HB26, uni
Pressed @ 800 psi

HB26 flat at both P
HB26 peak < SSII peak

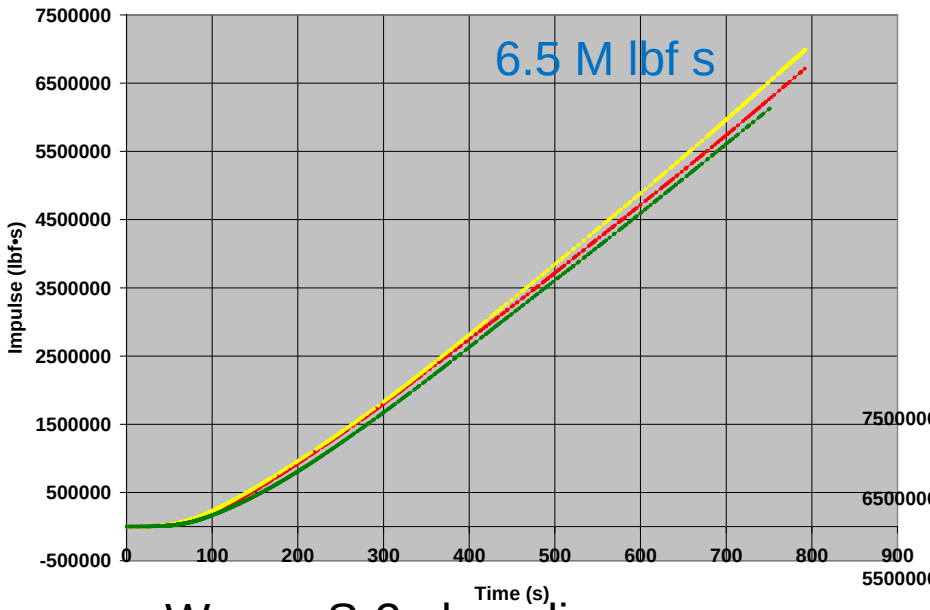
WL (HB26)< WL(SSII)

transverse compression strength HB26 > SSII`

Dyneema HB26, uni
Pressed @ 2700 psi



Impulse vs time (quasi-static)

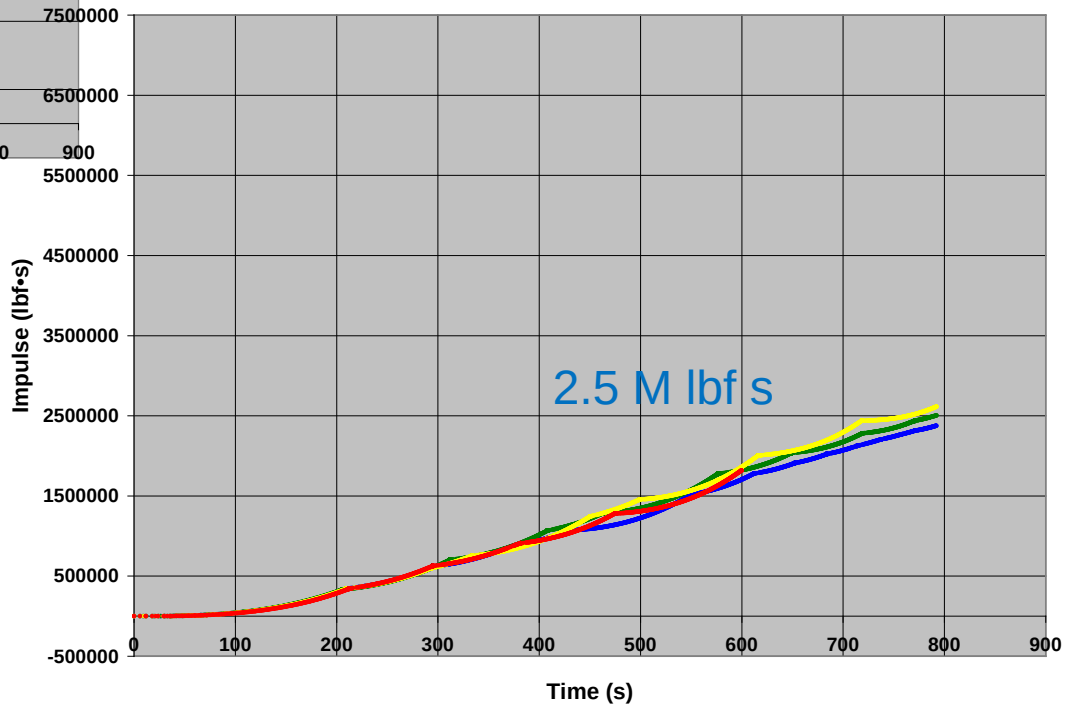


Woven S-2 phenolic

Impulse is the integrated resistance force over time (in this case all at constant cross-head rate of .0008 in/s

Note: quasi static impulse capacity of GRP greater than SSII at same time increment?

Spectrashield II uni



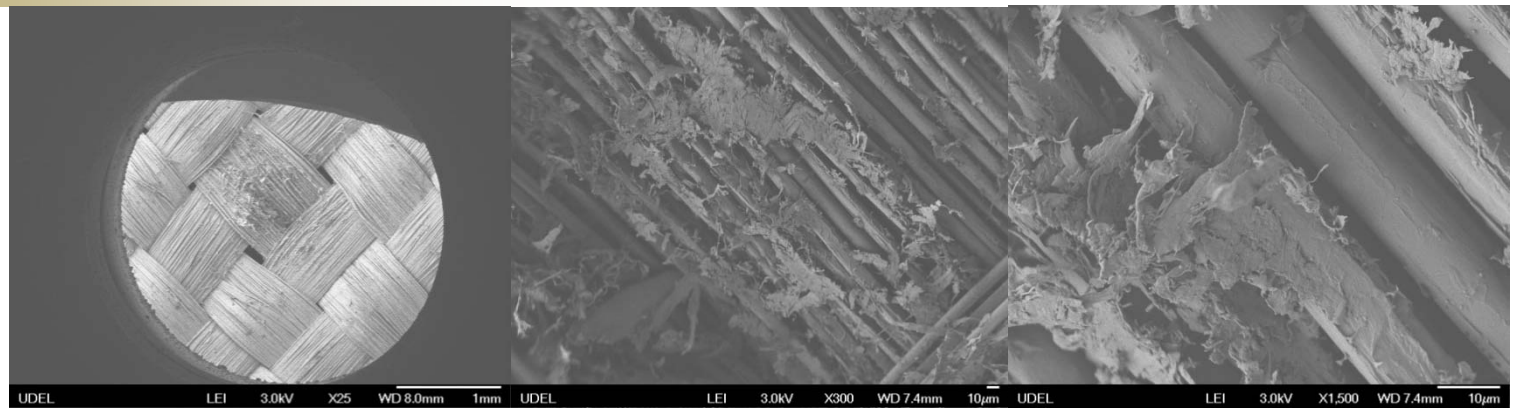
4 specimens each suggest reasonable reproducibility of each material test

Linear response suggests uniform load resistance cycle since time interval is constant

Summary of Observations

- Cyclic response more prevalent in uni constructions
- Aramids and UHMWPE exhibit similar behavior, glass laminate is unique (quasi-static)
- Cyclic response likely superposition of normal compression plus membrane
- Wavelength is consistent grouping of plies SSII > HB26
- Constant slope of impulse suggests uniform response per cycle
- Lamina thickness or matrix properties may influence wavelength (since HB26/SSII are different in resin system)
- With quasi-static loading, membrane contribution > compression
- Peak stress may correlate with ballistic efficiency since SSII has highest peak values
- High impulse capacity of GRP can be rationalized by normalizing response by density
- SSII may have apparent Szz lower than HB26, but perhaps higher membrane capacity

Implications on Penetration Resistance



Images of Kevlar filaments subject to low speed impact at increasing magnification levels (Courtesy of E Wetzel/ D. Kalman, ARL/Univ of Delaware)[13]

Previous studies have detailed even better examples of flattening and fibrillation of transversly compressed fibers: Phoenix, Textiles Research Journal 65:934-940, 1974 and Singletary, J, Jour. of Materials Sci., 35, (2000)

Soft response in transverse compression may not effect tensile strength (10,11)

Fibrillation or plastic flattening may allow for extended membrane stretching prior to rupture

Cunniff[14] suggests increased Ts with hydrostatic pressure

Hydrodynamic pressures may increase axial resistance (8)

Self confined compression may explain observations (8)(Scott/Cheeseman -2008 IBS)

Conclusions

- During confined compression testing, uni-directionals exhibited cyclic loading response
- High penetration resistance may correlate with high hydrostatic pressures or increased membrane stretching and rupture
- The cyclic behavior is constant thru thickness
- The failure modes involving fiber axial tensile strength and transverse compressive strength appear to be uncoupled (10,11)
- Increases in rupture strength were observed with higher consolidation pressures