UNIVERSITY OF CAMBRIDGE

Cavendish Laboratory
Fracture & Shock Physics

Split Hopkinson Pressure Bar Studies of a Nitrocellulose-based PBX System

AWE Nitrocellulose Meeting

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Overview

- Materials: EDC37 and NC-K10
- Technique: Split-Hopkinson Pressure Bar with Pulse Shaping and Temperature Control.
- Results & Discussion

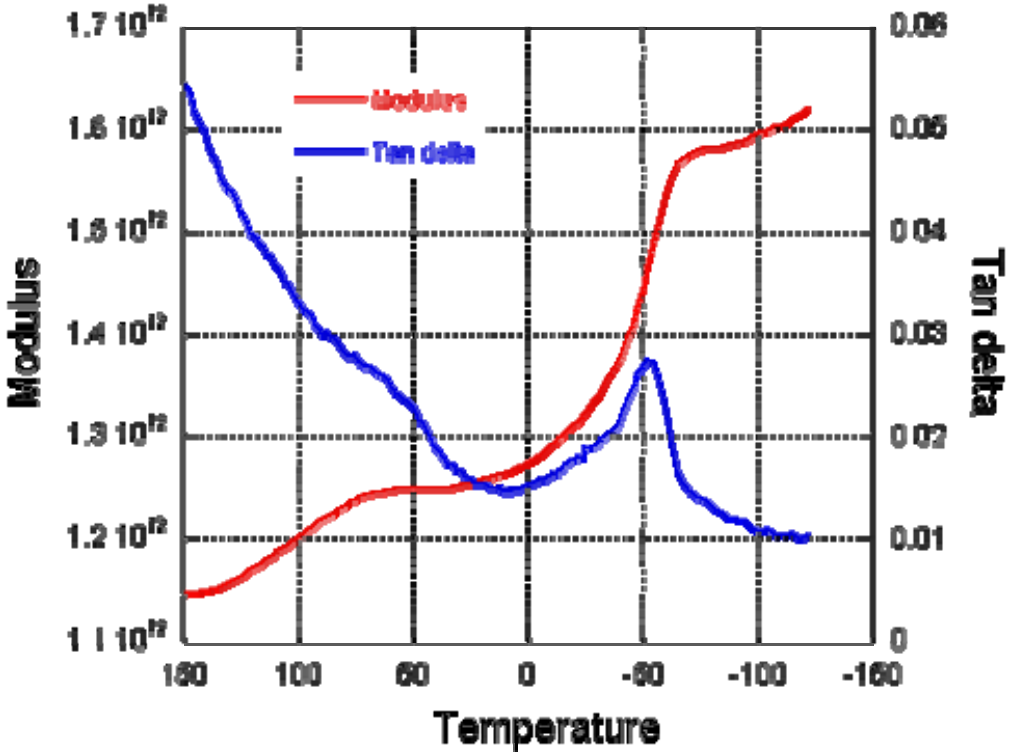
Sample Materials

Sample Materials

EDC37: 91% HMX filler, 9% NC-K10 binder

NC-K10: plasticised nitrocellulose

Motivation: examine sub-T_g behaviour to extend current data set.



DMTA figure courtesy of Dr D. Williamson

Story So Far

- We already have EDC37 data for:

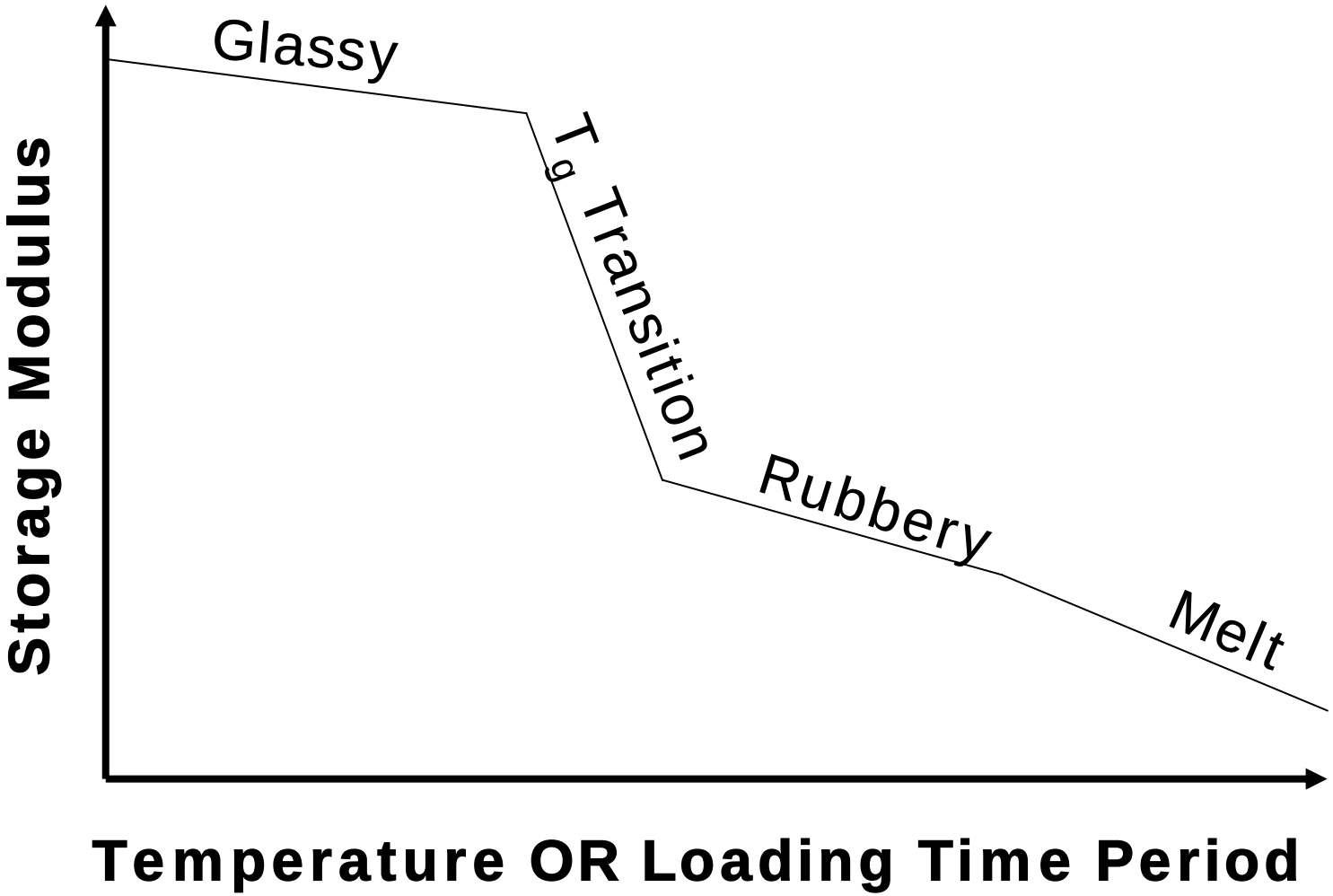
Fixed **T** (room temp), varying **strain rates**

Fixed **strain rate** ($10^{-3}\ s^{-1}$), varying **T**

(D.M. Williamson et. al., *paper awaiting publication)*

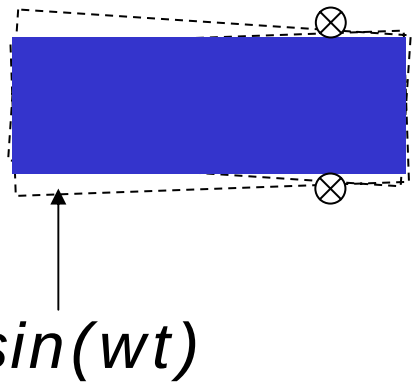
... ramp up strain rate, drop T, see what happens...

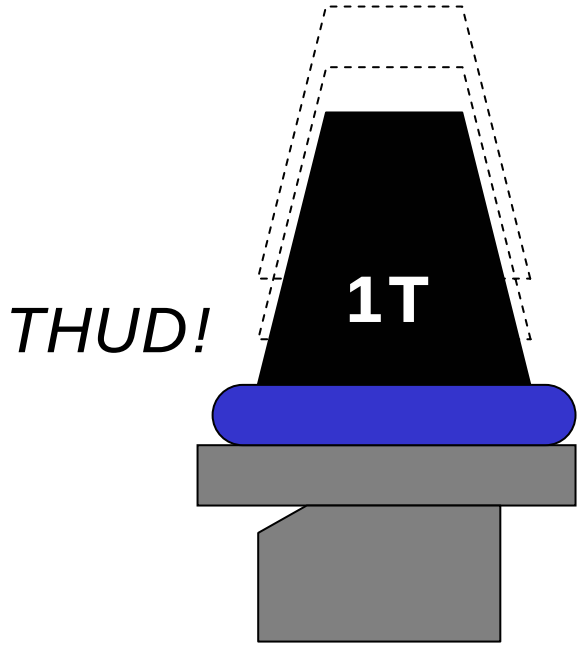
Viscoelastic Response



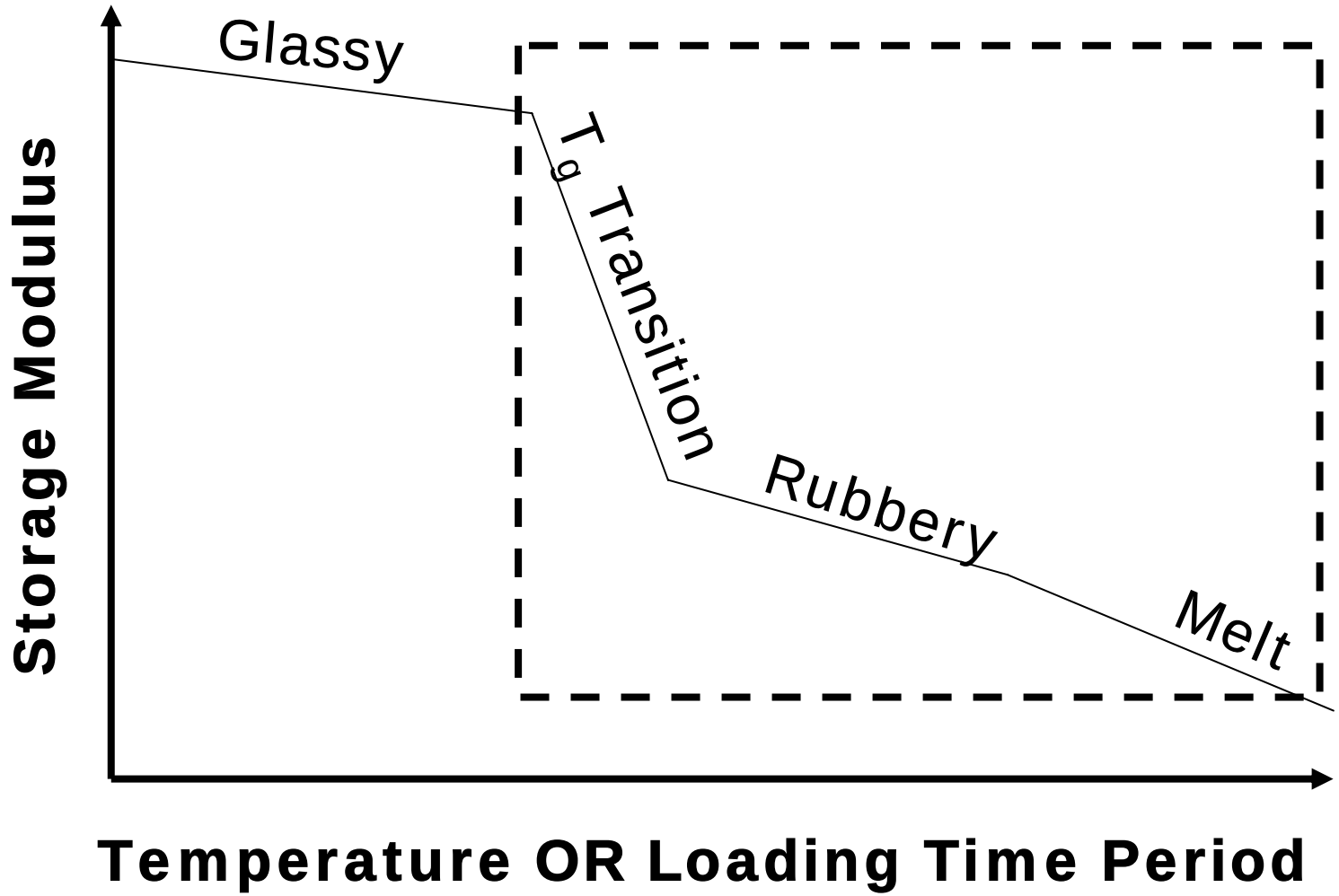
Not-so-subtle differences…

- Strain Rate vs. Loading Frequency
- Small strain vs. strained to failure
- Pure polymer vs. filled polymer…





Current Data...

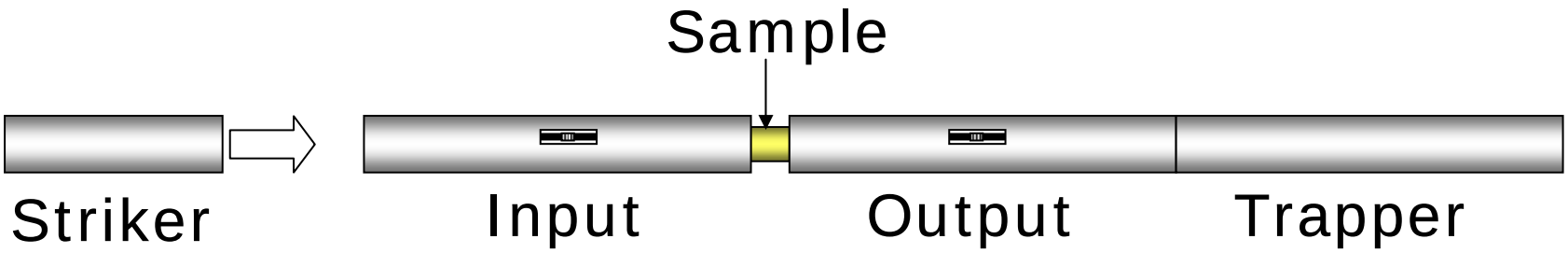


Plan…

- Use high strain-rate apparatus to raise the transition temperature
- Use cooling chamber to induce glassy behaviour
- Find something out.

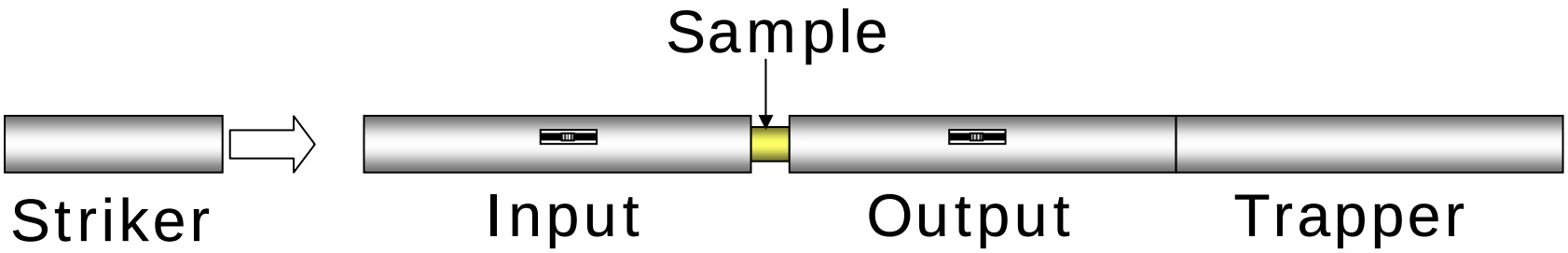
Apparatus

Split Hopkinson Pressure Bar

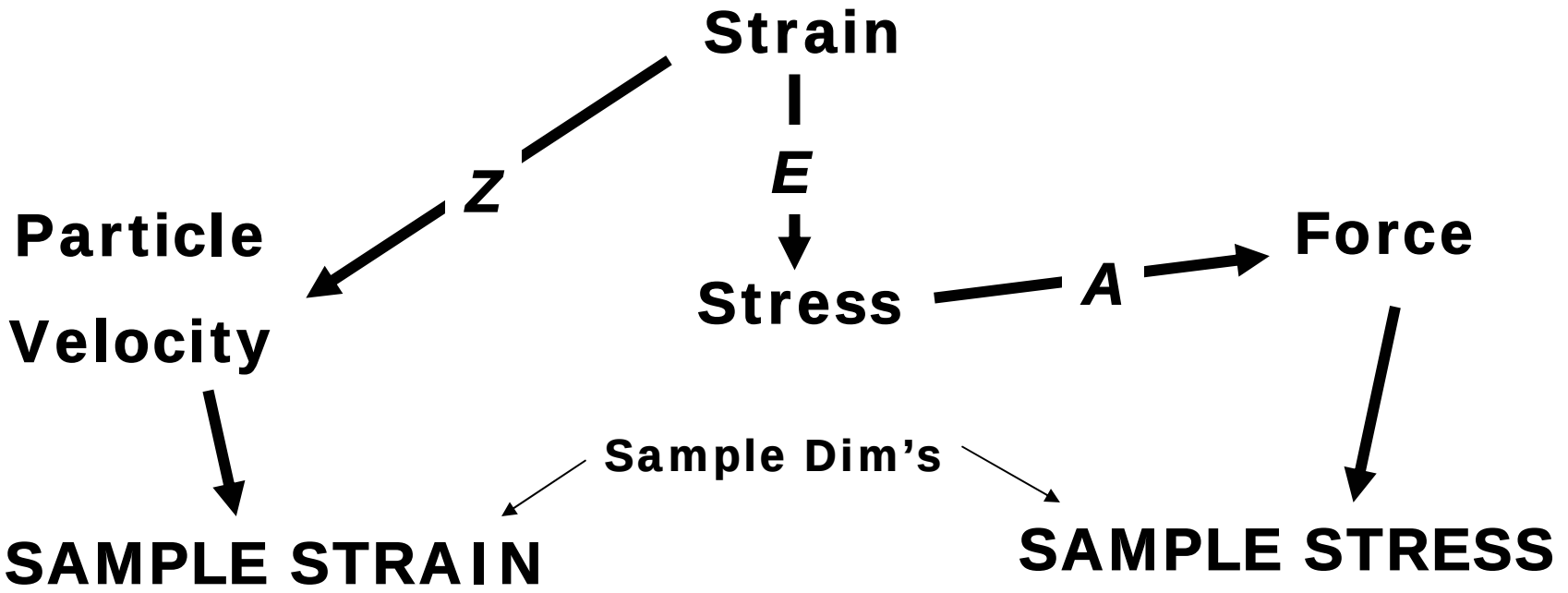


Gauges measure strain in Bars

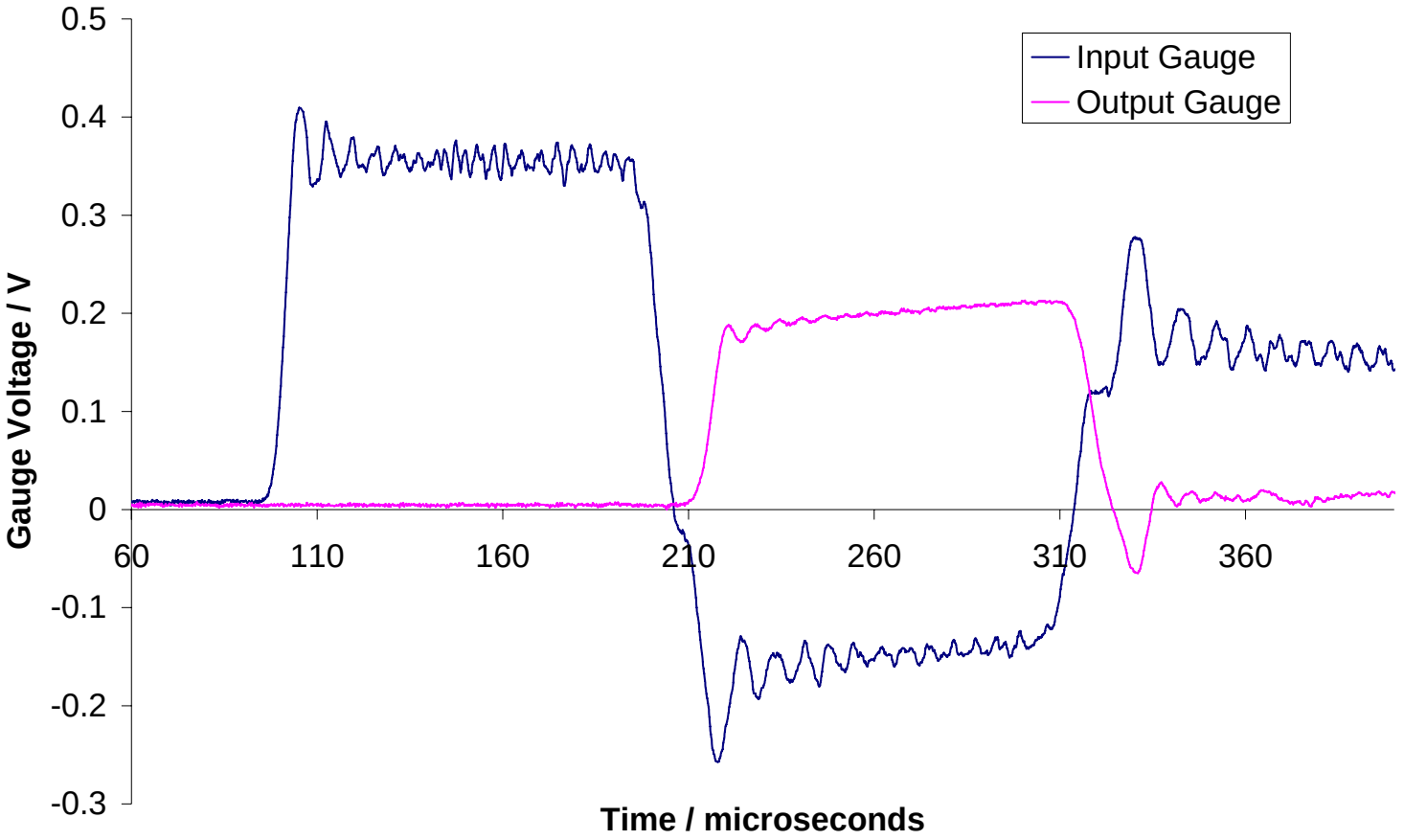
Split Hopkinson Pressure Bar



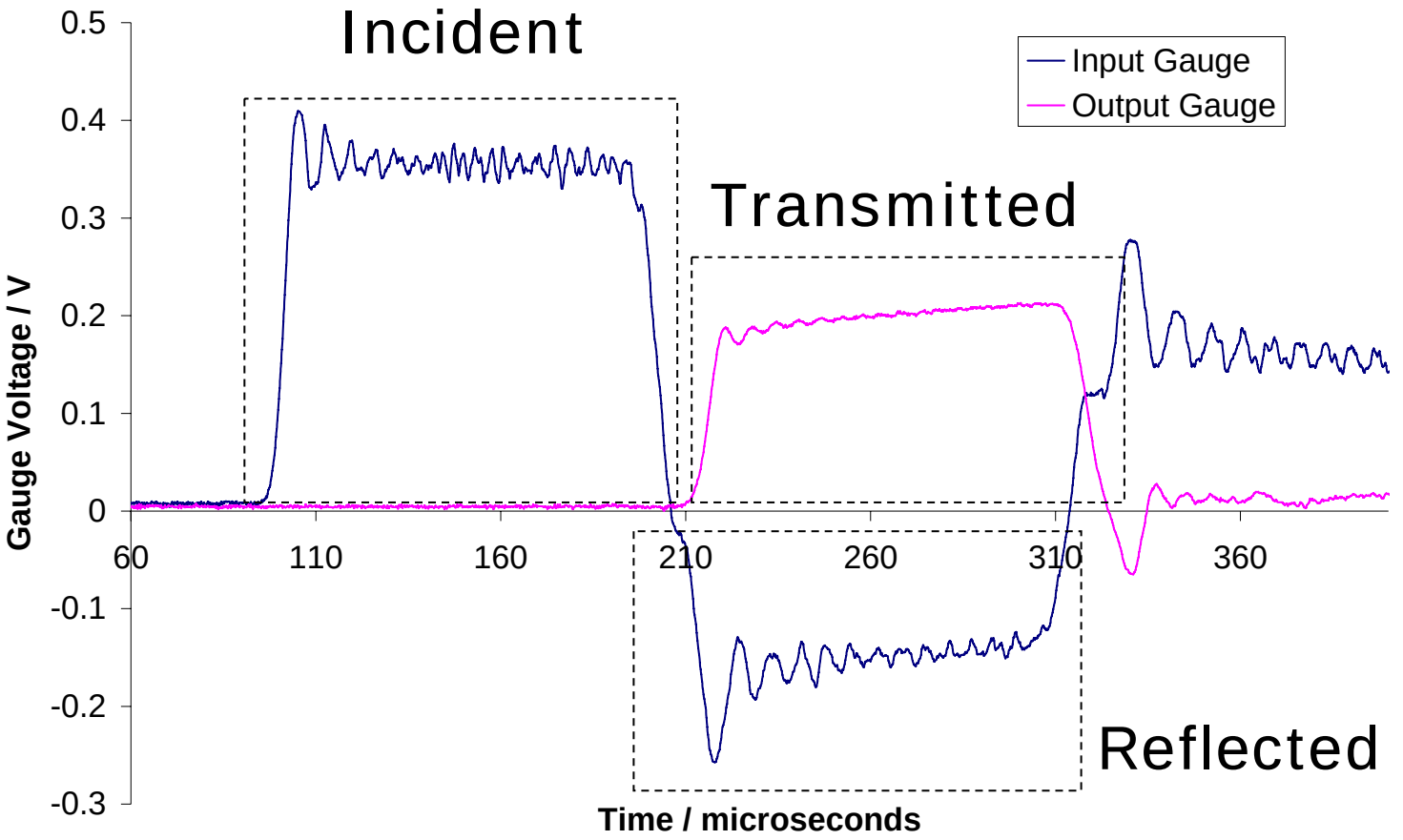
Gauges measure strain in Bars



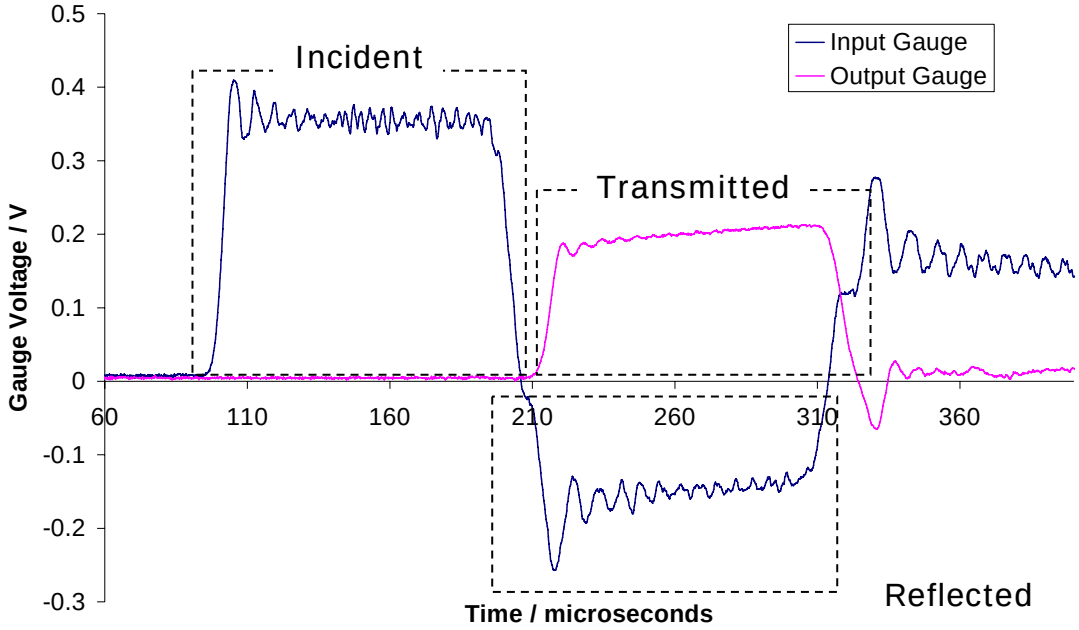
Split Hopkinson Pressure Bar

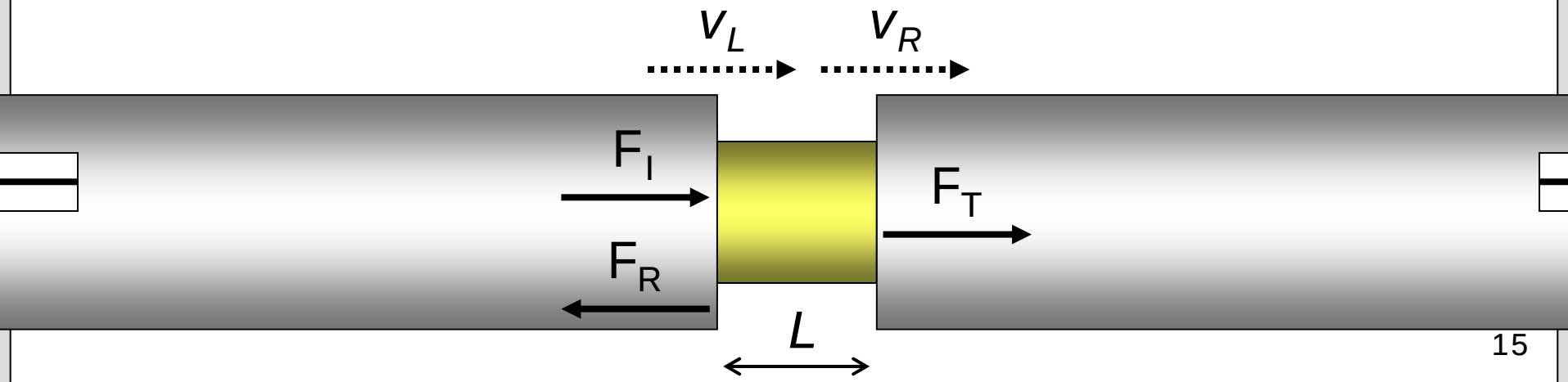


Split Hopkinson Pressure Bar



Split Hopkinson Pressure Bar



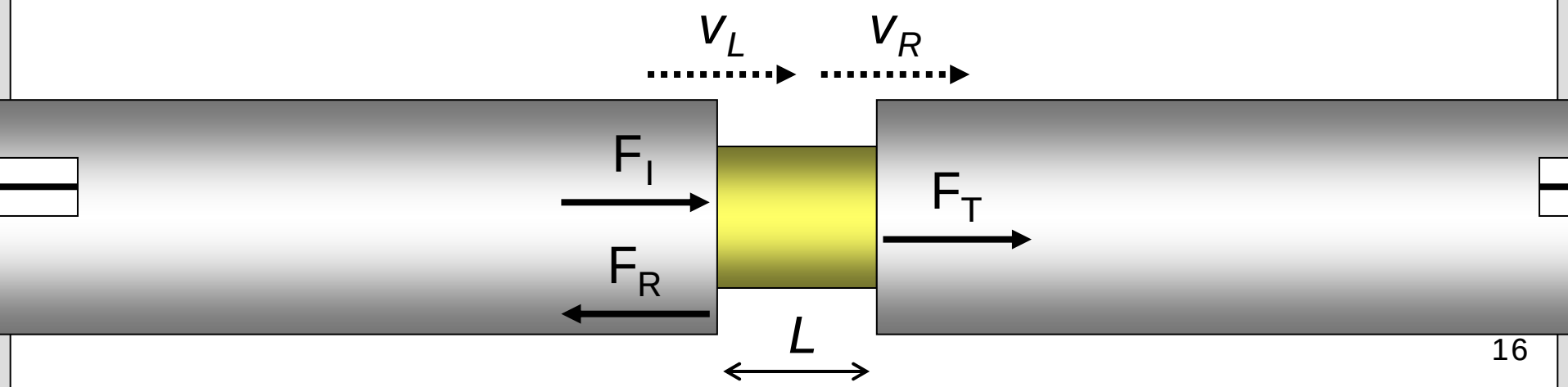


Split Hopkinson Pressure Bar

$$\dot{\varepsilon} = \frac{v_R - v_L}{L}$$

$$\sigma = \frac{F_T}{A_S}$$

(assumes equilibrium)



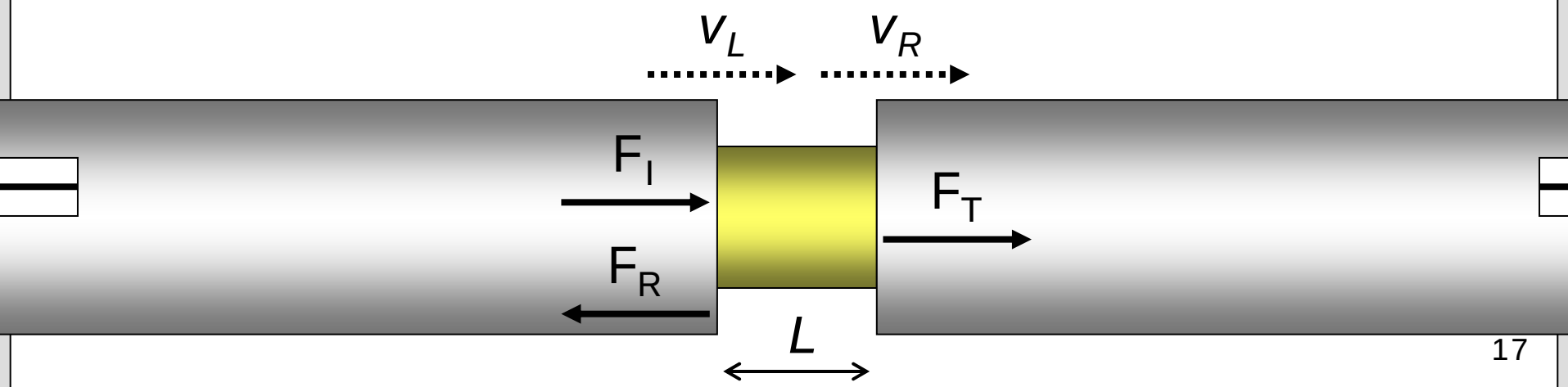
Split Hopkinson Pressure Bar

$$\sigma_R = \frac{F_T}{A_S}$$

$$\sigma_L = \frac{F_I + F_R}{A_S}$$

Do Front and Back stresses match?

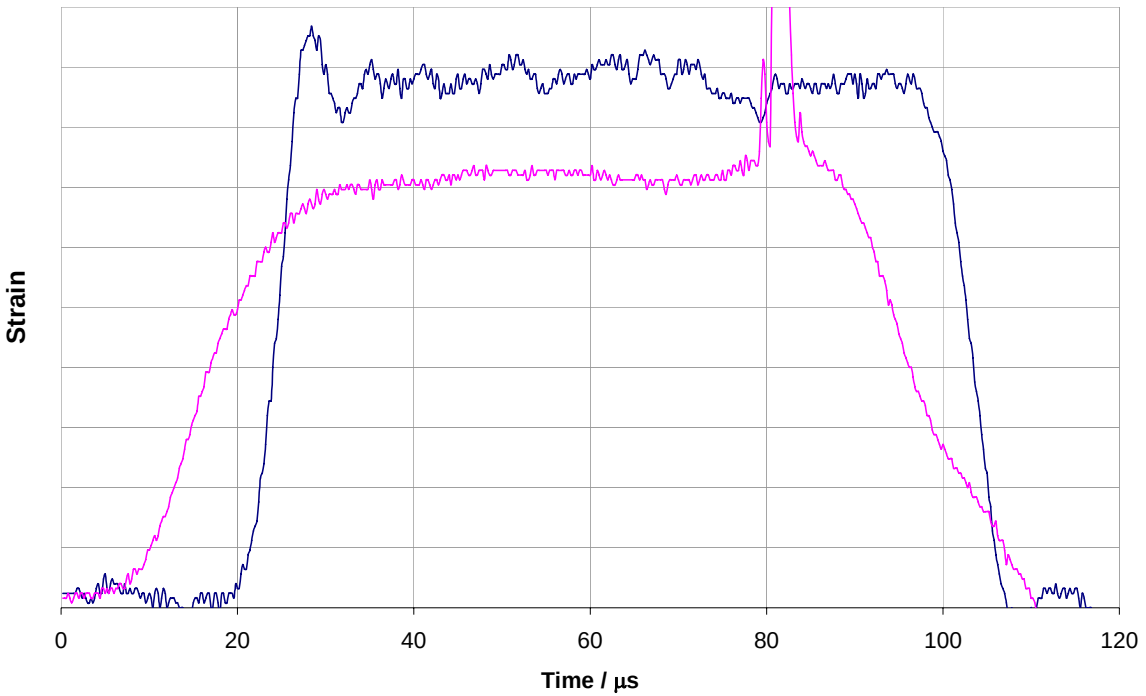
...if not, we have a problem



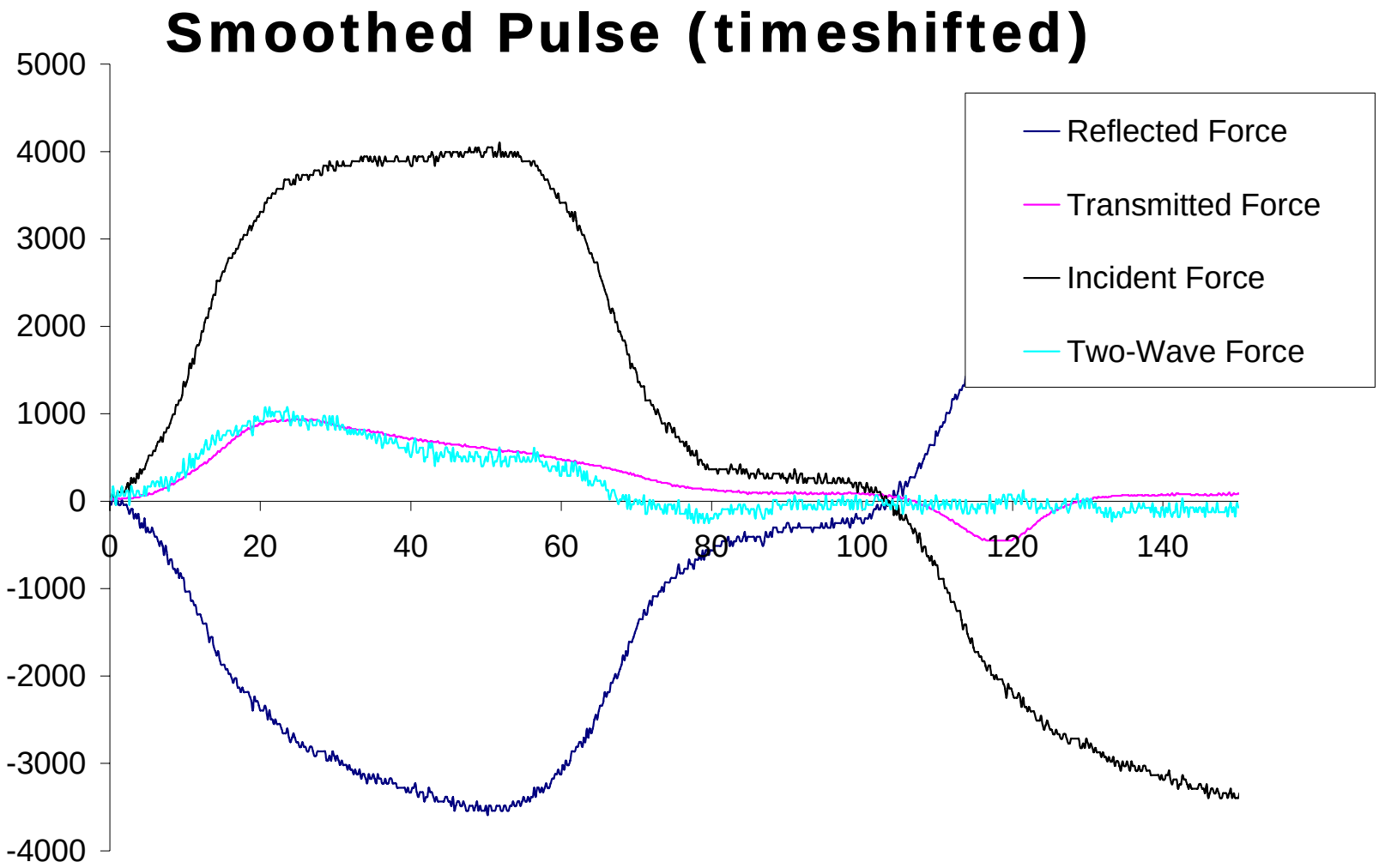
Split Hopkinson Pressure Bar

Shallower Pulses = Reach Equilibrium Sooner

- **Copper Shim (annealed at 450C for 2hrs)**
- **Place on end of input bar to cushion blow**



Split Hopkinson Pressure Bar

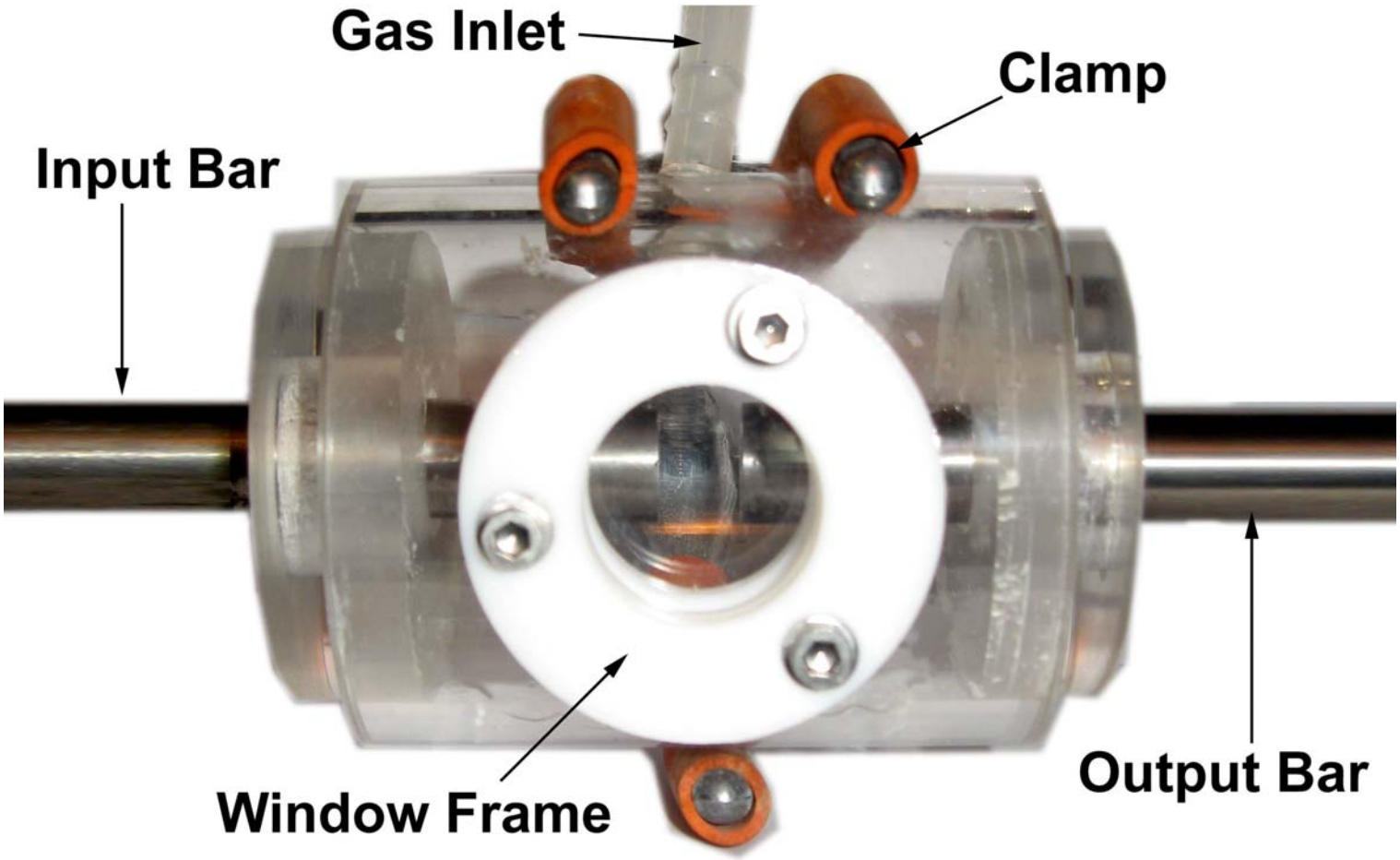


Other considerations

- **Friction**. Mitigate by lubrication with appropriate substance (silicon grease)
- **Inertia**. Demonstrated* to be negligible for strain rates below $10^5 s^{-1}$ provided sample geometry is sensible.

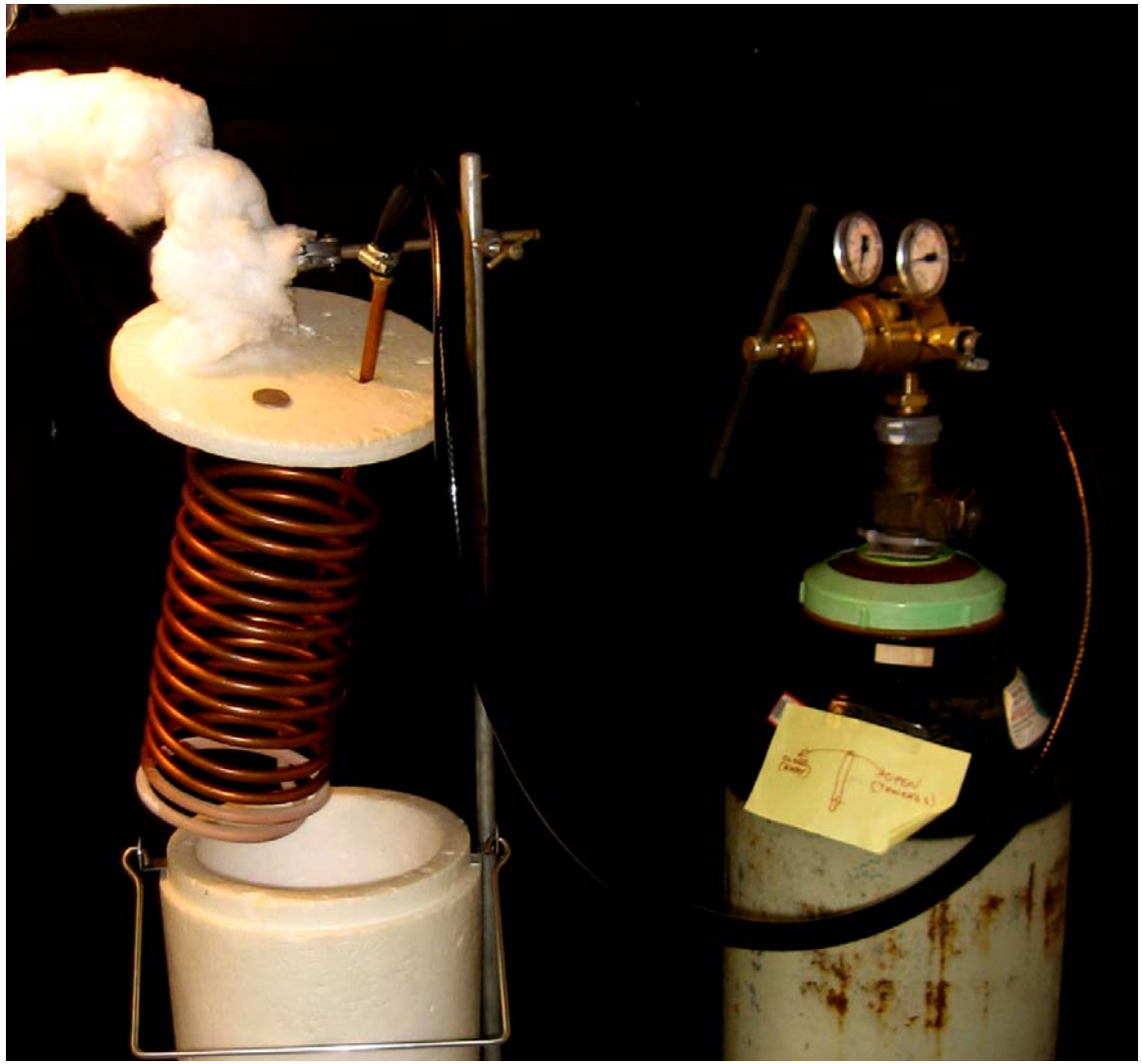
*G.T. Gray III (2000) – ASM Handbook vol. 8

Heating / Cooling System



Thermocouple on output bar.

Heating / Cooling System

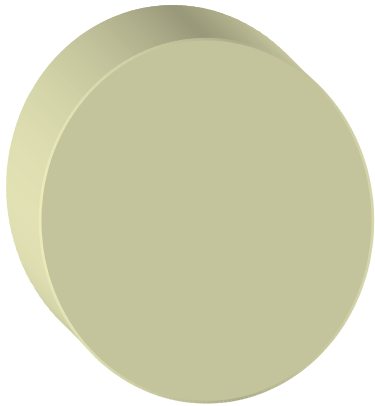


EDC37 Samples

Supplied in disc form by AWE

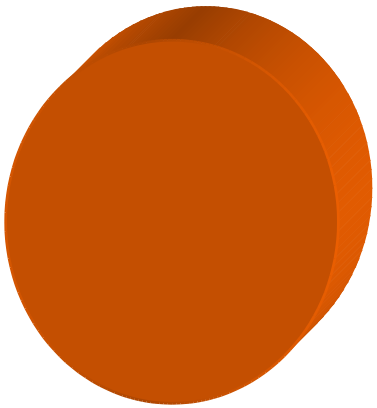
3mm Length

8mm Diameter



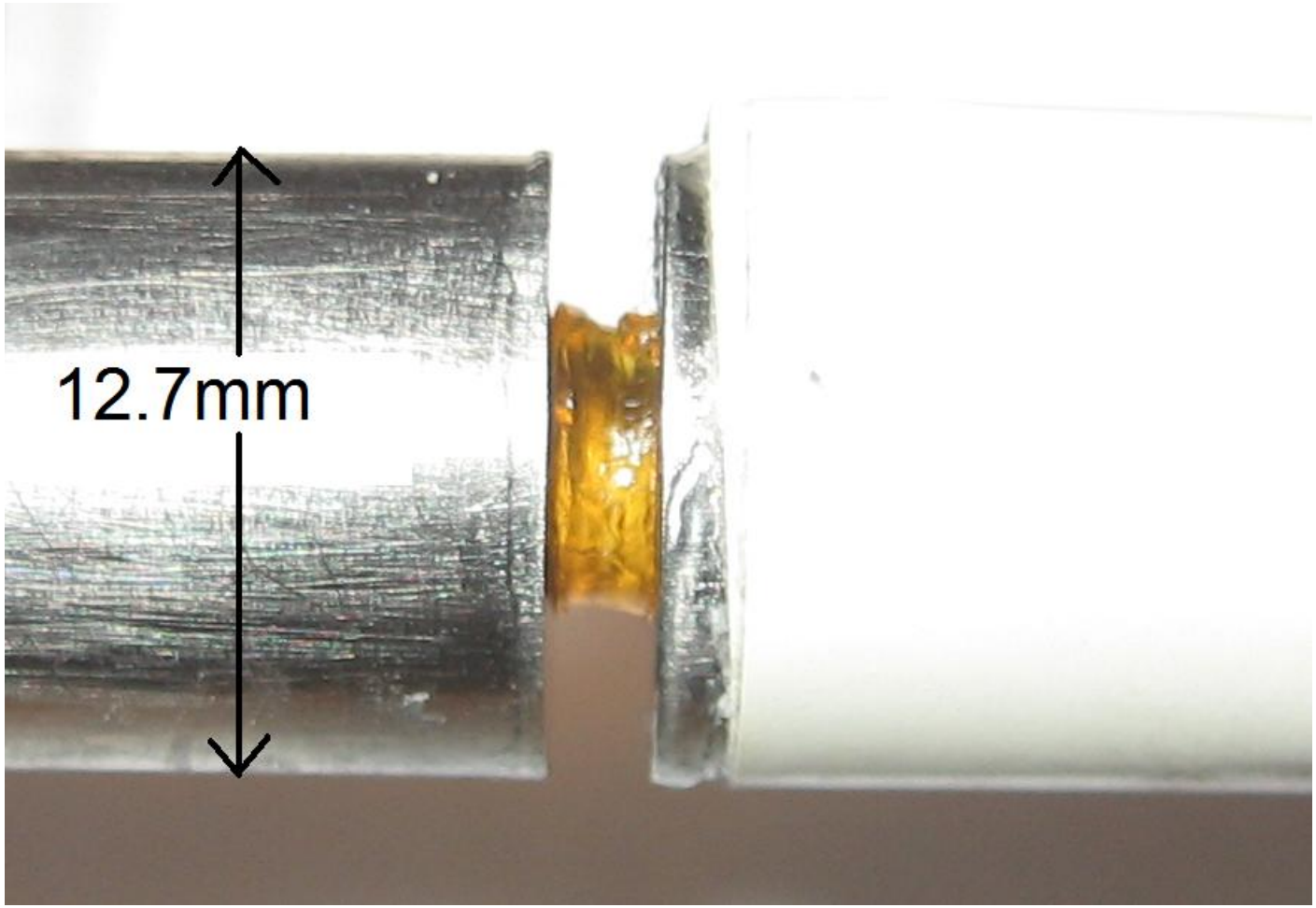
NC-K10 Samples

Supplied as ~1mm thick sheets by AWE

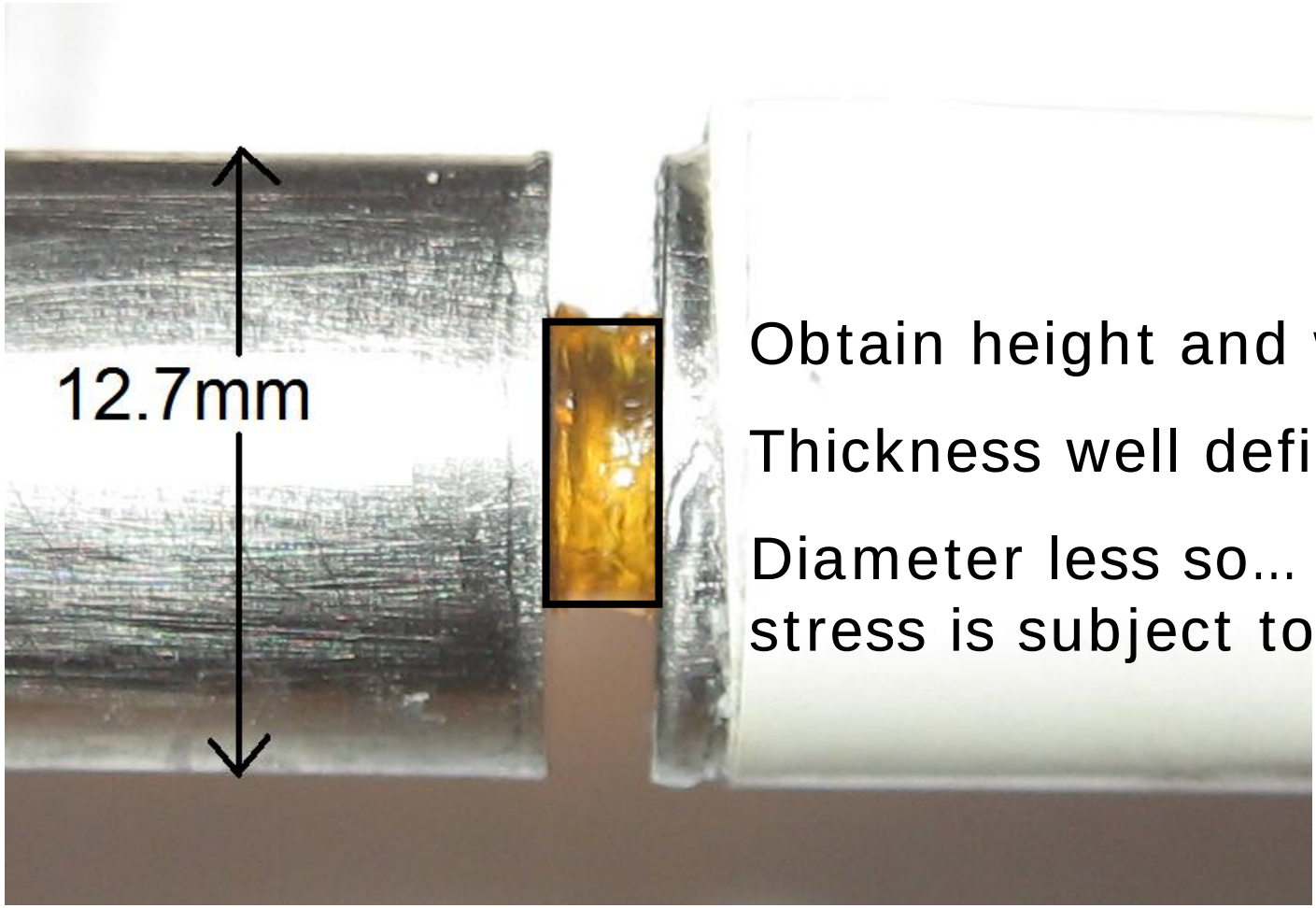


- Make double-thickness sheet
- Punch out ~3mm diameter discs
- Place between lubricated bars and squeeze
- Measure dimensions using sophisticated multichromatic photometric array

NC-K10 Samples



NC-K10 Samples



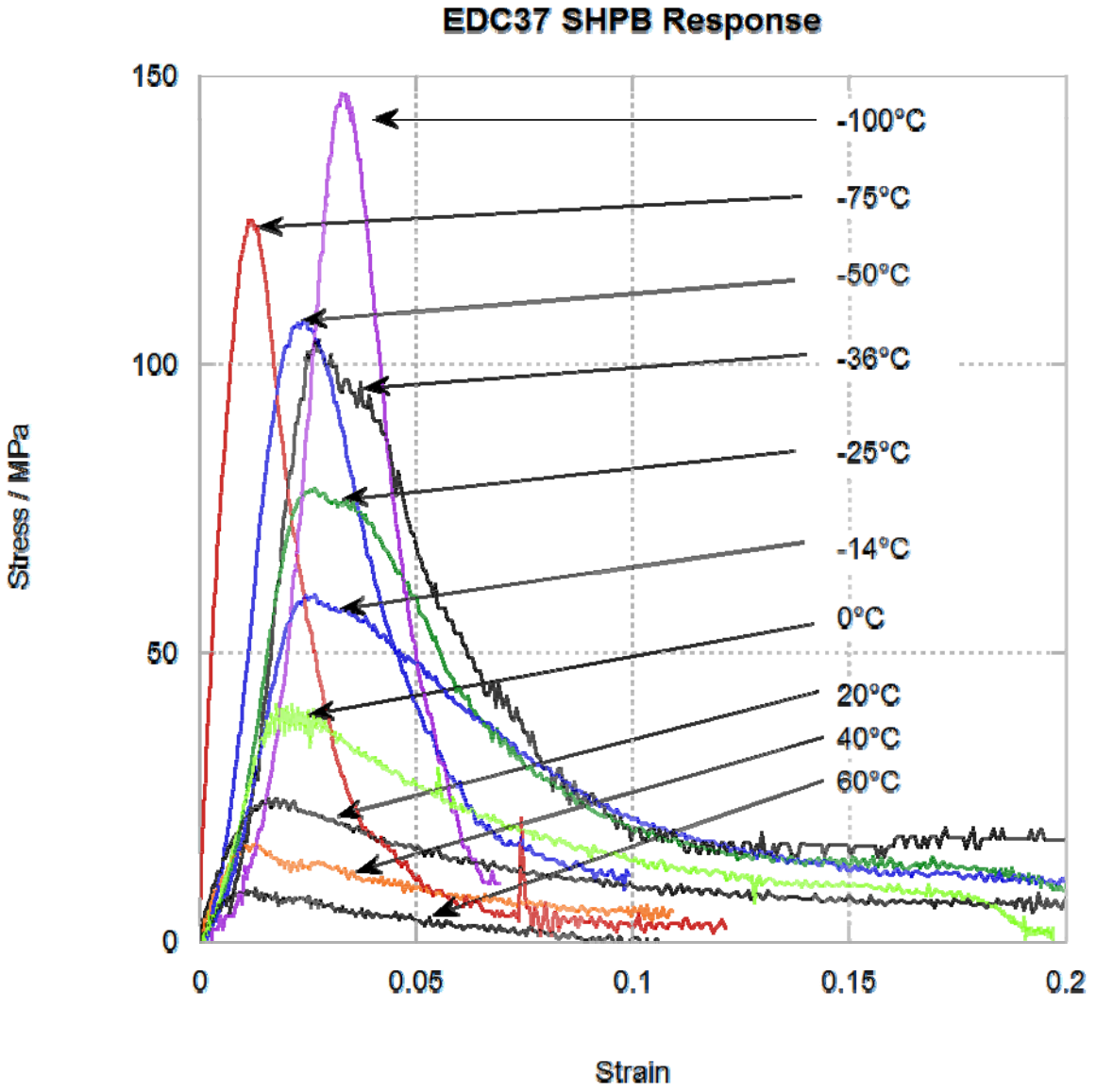
Obtain height and width.

Thickness well defined…

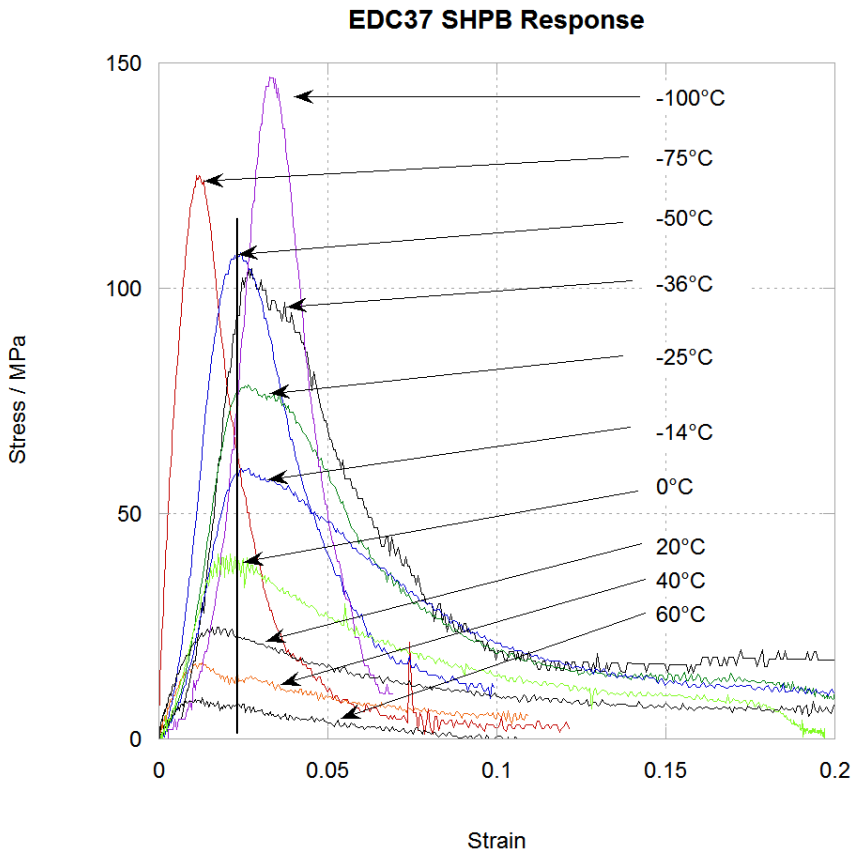
Diameter less so… hence stress is subject to error

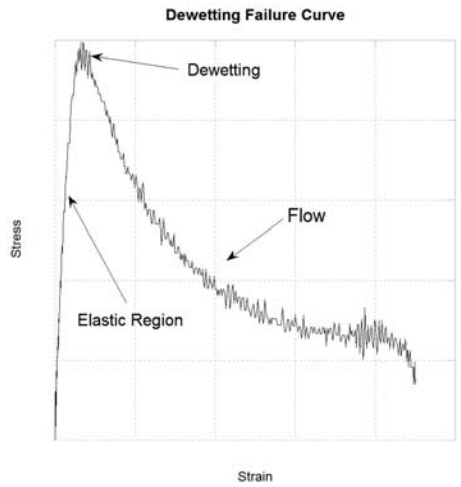
Results

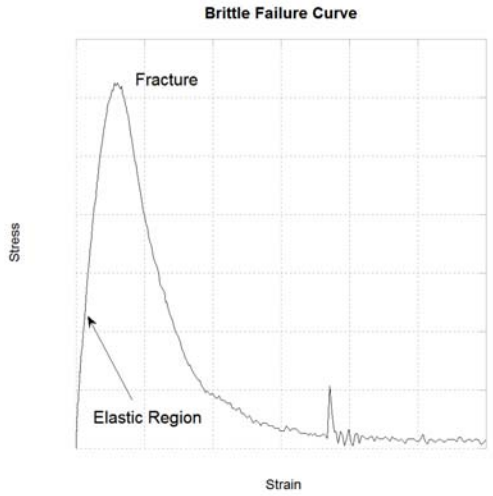
EDC37 Results



Failure





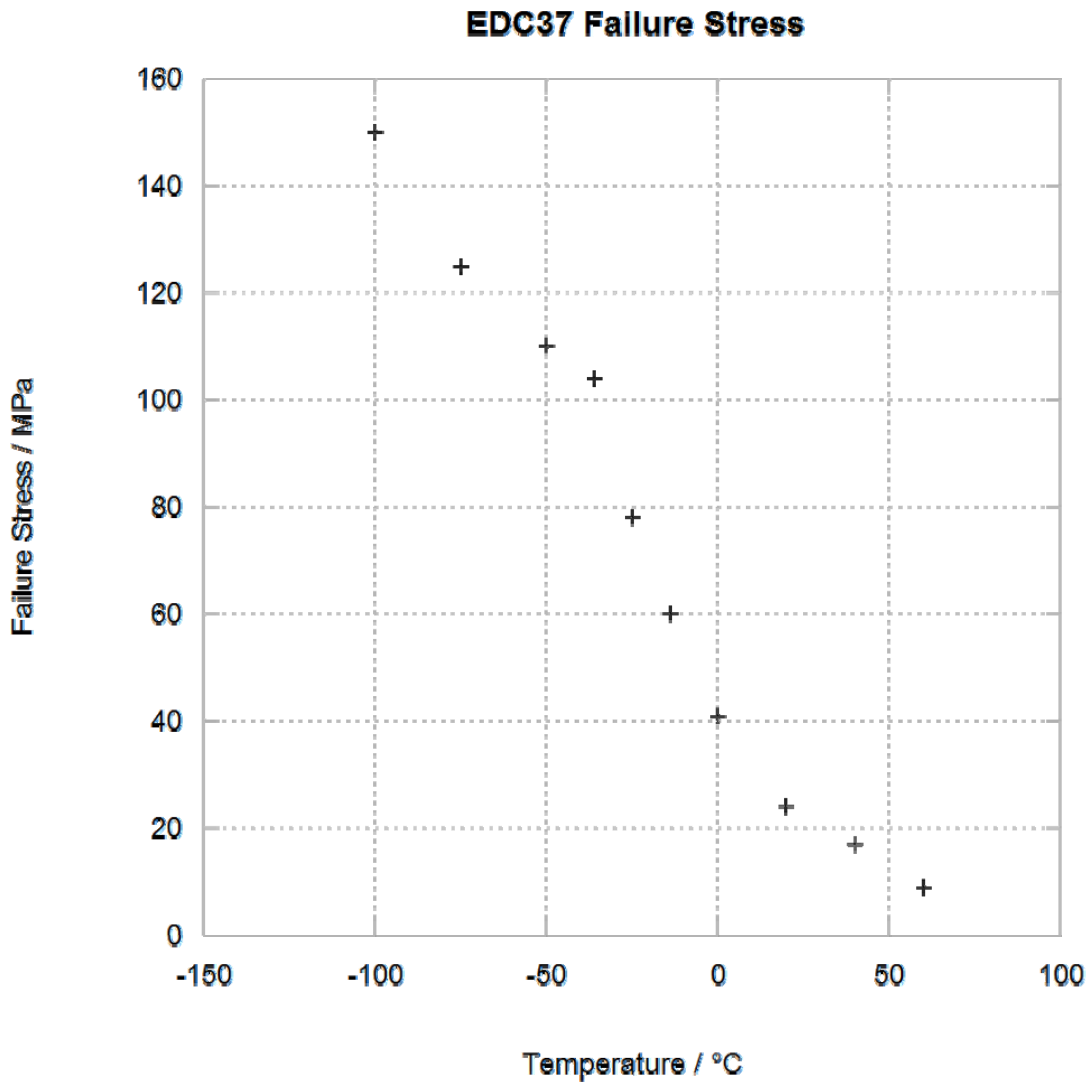


Near-constant failure strain

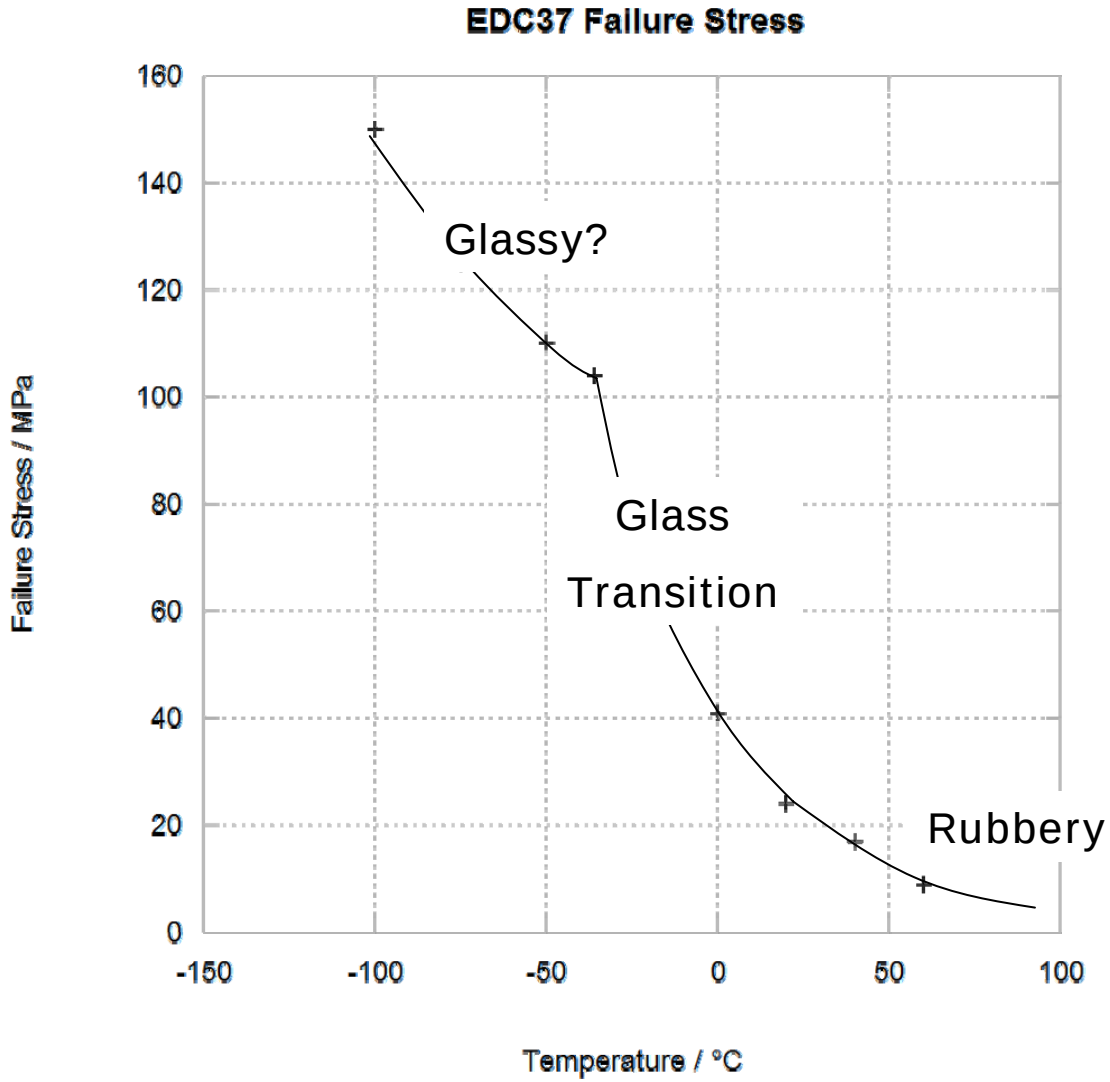
EDC37 Results

Sample	Length / mm	Temperature / $^{\circ}C$	$\dot{\varepsilon}$ / s^{-1}	σ_y / MPa
E3	3.20	60	2500	9
E10	3.19	40	1800	17
E6	3.19	20	3000	24
E8	3.19	0	1900	41
E5	3.21	-14	2300	60
C9	3.00	-25	2300	78
C5	3.00	-36	2400	104
C7	2.98	-50	2100	110
C2	2.99	-75	2000	125
C10	2.99	-100	2400	150

EDC37 Strength



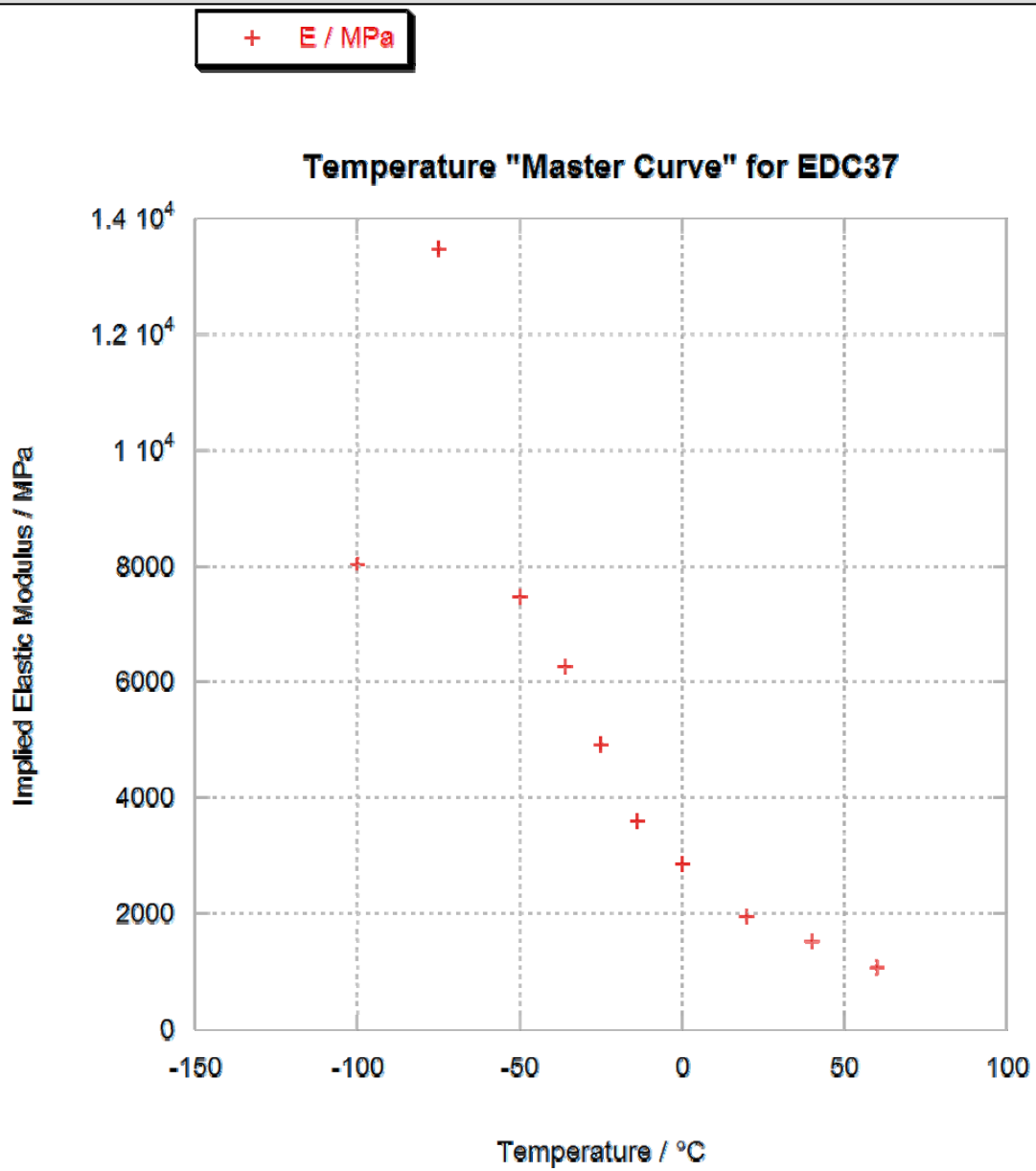
EDC37 Strength



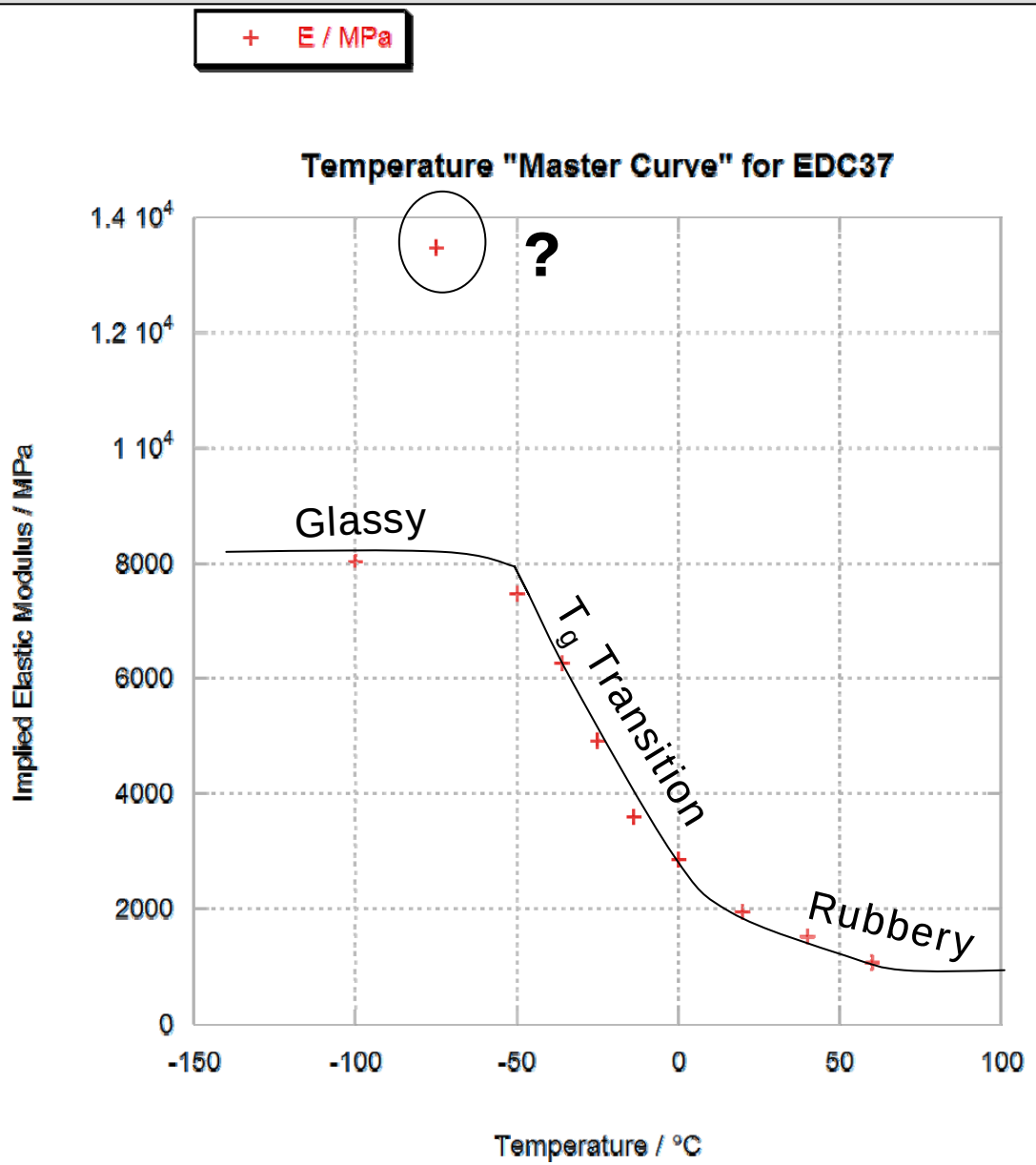
EDC37 Modulus Estimate

- Usually, elastic behaviour occurs before sample equilibrium reached
- Pulse Shaping allows earlier equilibrium
- Stress-strain gradient offers estimate of elastic modulus

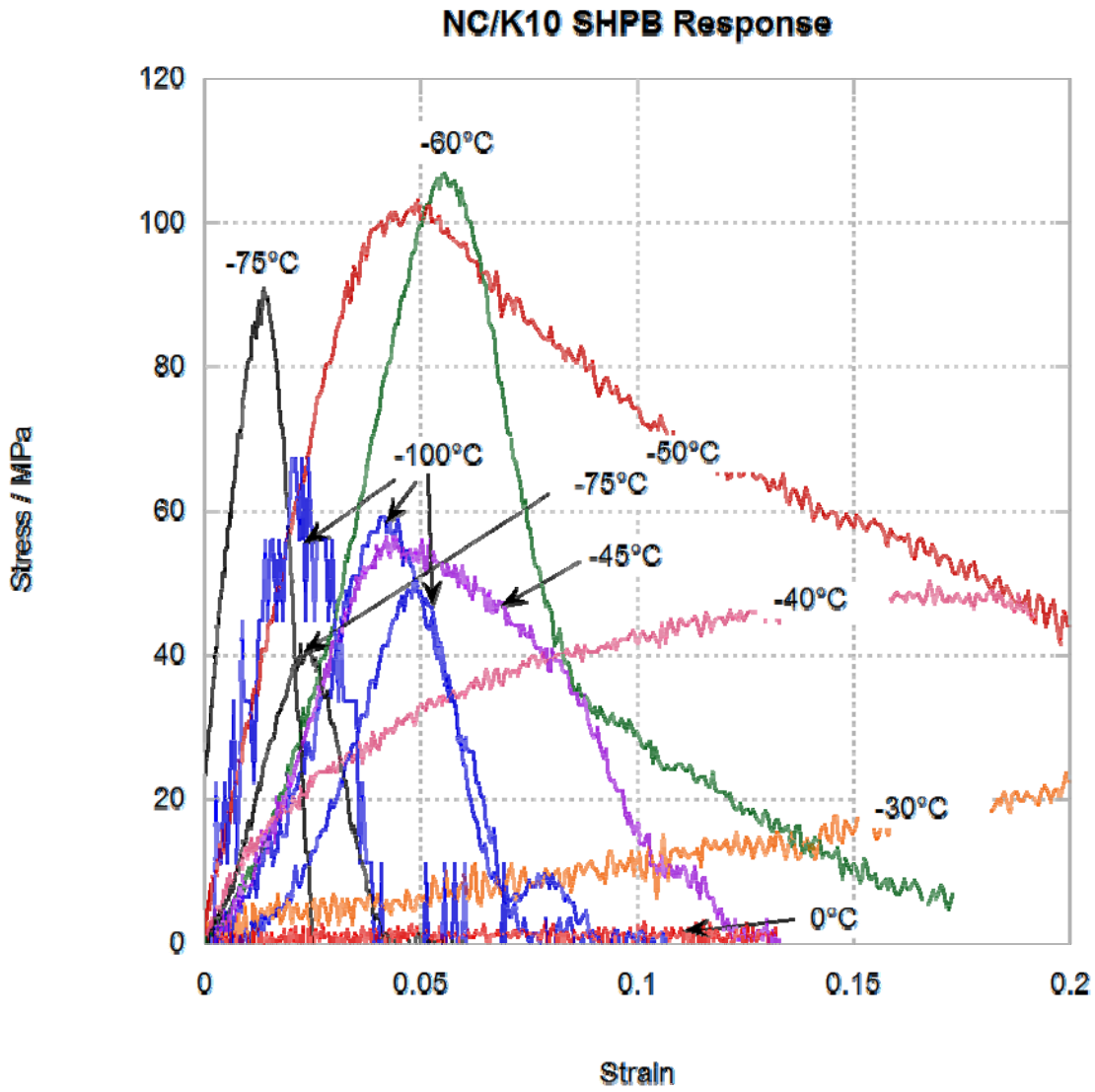
EDC37 Modulus Estimate



EDC37 Modulus Estimate



NC-K10 Results



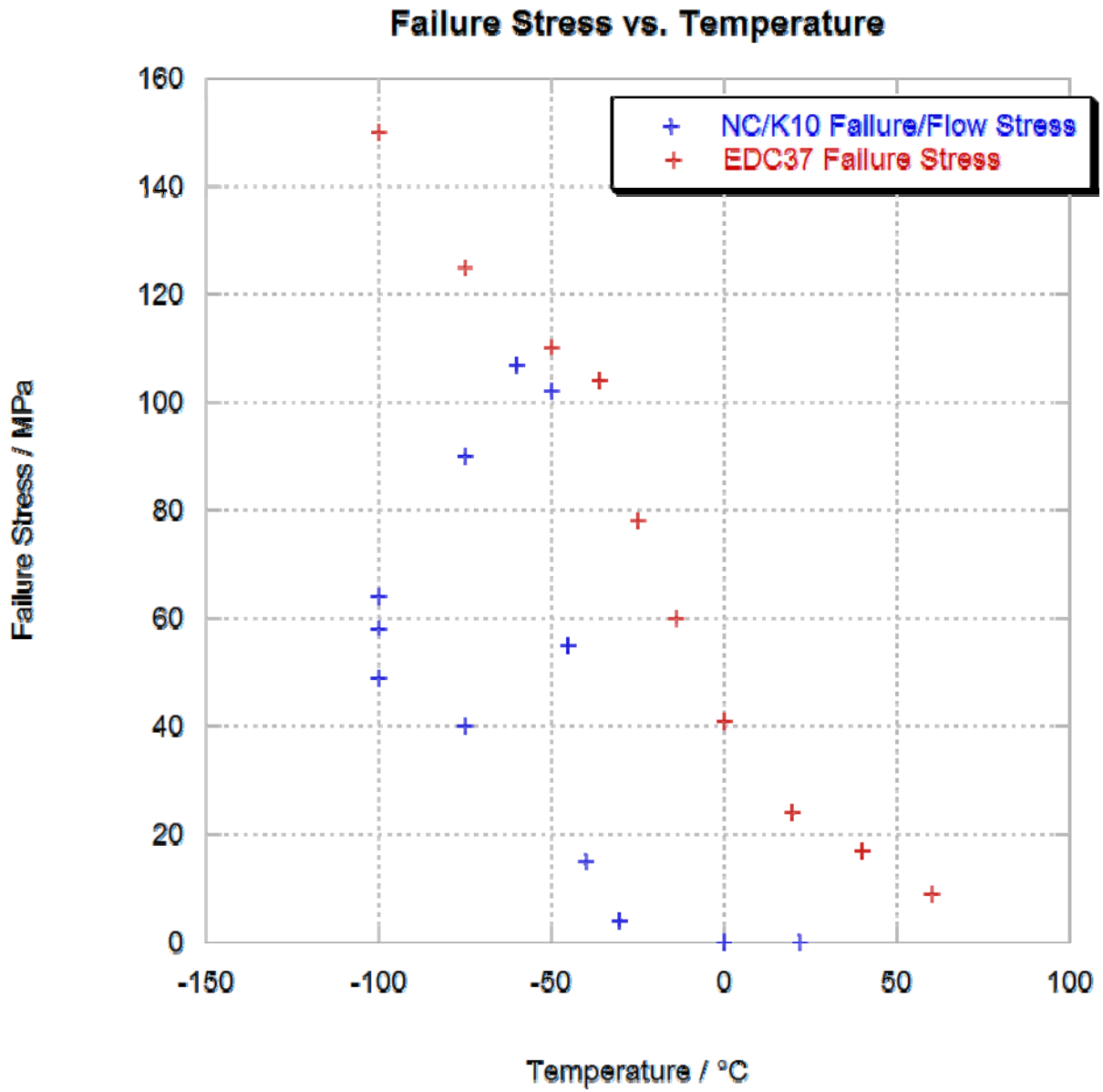
NC-K10 Results

Sample	Length / mm	Diameter / mm	Temperature / $°C$	$\dot{\varepsilon}$ / s^{-1}	σ_y / MPa
NC2	2.0	5.0	22	0	-
NC12	2.9	5.9	0	0	2200
NC11	2.2	6.1	-30	4	2600
NC10	2.1	5.2	-40	15	2800
NC13	2.0	5.0	-45	55	2100
NC9	2.3	5.0	-50	102	3000
NC8	2.5	5.9	-60	107	3000
NC6	2.3	4.5	-75	90	3700
NC7	2.1	4.9	-75	40	3100
NC3	2.0	5.0	-100	64	3500
NC4	1.9	5.2	-100	58	3500
NC5	2.3	5.6	-100	49	1700

"Yield Stress" taken as zero for "melt"

Stresses have near 10% error from poorly defined sample diameter/area

Combined Strength Results



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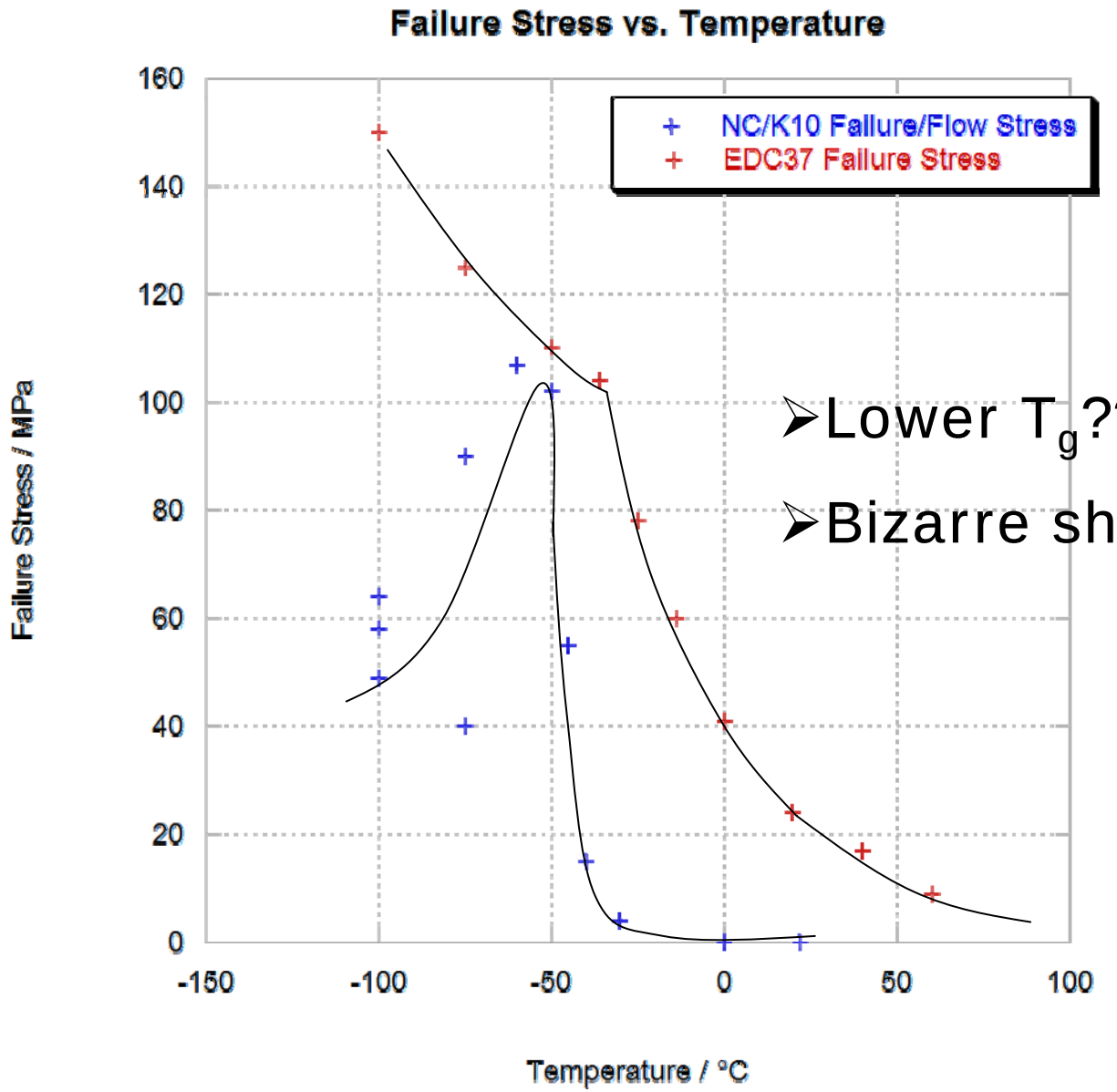

- Lower T_g??
- Bizarre shape

Conclusions

- Hopkinson Bars allow detailed study of viscoelastic effects in high rate impact around the glass transition
- EDC37 Failure Stress continues to rise below T_g
- High rate modulus estimates describe a near-ideal viscoelastic master curve at low strains
- NC-K10 Failure Stress peaks at T ~ -60C, then decreases
- Binder transition at lower T than EDC37, sharper

Extension

- Cold machining to produce better NC-K10 specimens from new material
- High-speed photography and soft-recovery techniques to confirm failure modes
- Simultaneous diametric measurements to find Poisson's Ratio
- Investigate crystal behaviour at low temperatures

Acknowledgments

- D.R. Drodge and D.M. Williamson thank AWE
- W.G. Proud thanks QinetiQ