The Zero-Span test- What are we measuring?

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Topics to be covered

- Fibre property measurements
- Zero-span introduction
- Experimental research
  - Zero span strength
    - Effect of test variables
    - Intrinsic strength/testing recommendations
  - Subtraction technique
    - Effect of test variables
    - Recommendations for testing
- What are we measuring?
  - Comparison between zero-span and single fibre data
- Other issues

Measurement of key basic fibre properties- the state of the art

- Fibre length ☺☺
  - Optical analysers
- Fibre wall, lumen area, width, thickness☺
  - Confocal microscopy
  - Embedding
- Fibre coarseness and fibre width☺
  - Optical fibre analysers
- Fibre mechanical properties☹
  - Strength, stiffness, stretch
  - Fibril angle variation
  - Cross-section dimension variation
  - Fibre defects

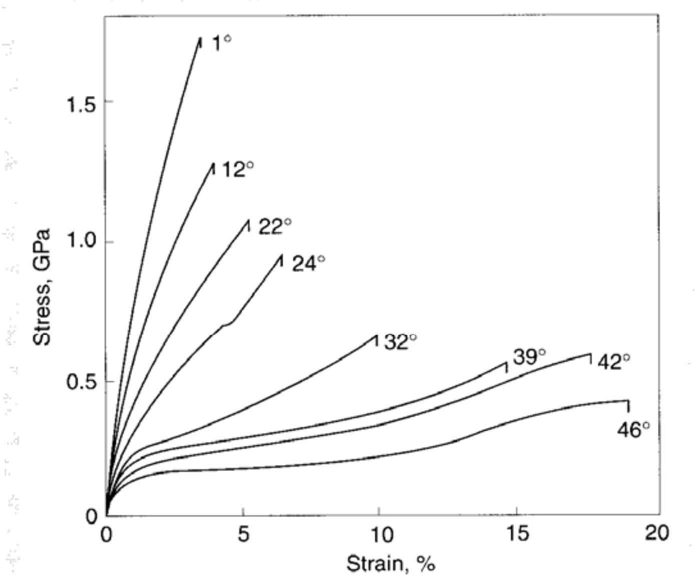

Figure 11. Load-elongation curves for black spruce fibers (45% yield kraft) with different fibril angle, measured using 1.2 mm span[20].

Taken from “Paper Physics”

Single fibre strength measurements

- Fibre separation, drying and hornification
- Fibre damage during mounting?
- Uniaxial load?
- Cross-section, fibril angle measurement
- Small loads and displacements
- Representative? Need MANY measurements
- **Tedious and difficult**

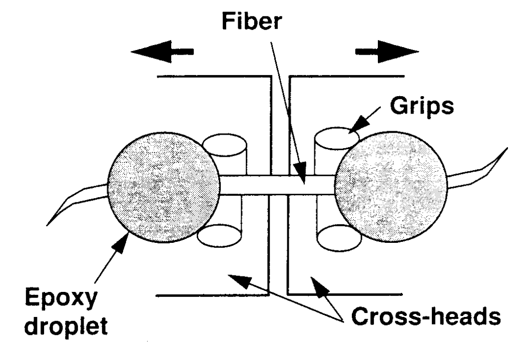

Figure 1. Schematic of individual wood fiber with epoxy droplets residing in the gripping assembly of the miniature tensile testing apparatus.

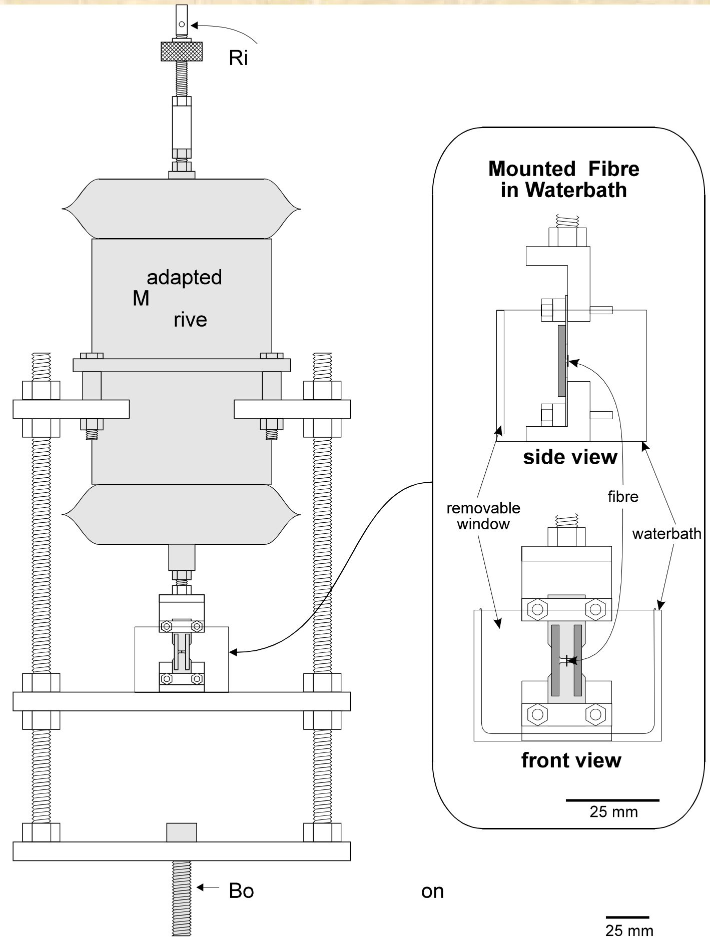

Fig 1. Attachment for single fibre tensile tests.

Taken from Groom (1995)- left
Conn (1999)- top

Zero-span measurements

- Pros
  - Rapid measurement.
  - Related (in some way!) to average fibre strength
  - 1000's of fibres broken per test.
  - Affected by fibre defects
- Cons
  - What are we measuring?
    - Stress transfer from jaw
  - Breaking strength only
    - Stretch and modulus?
    - Subtraction method
  - Average only
  - Affected by fibre defects

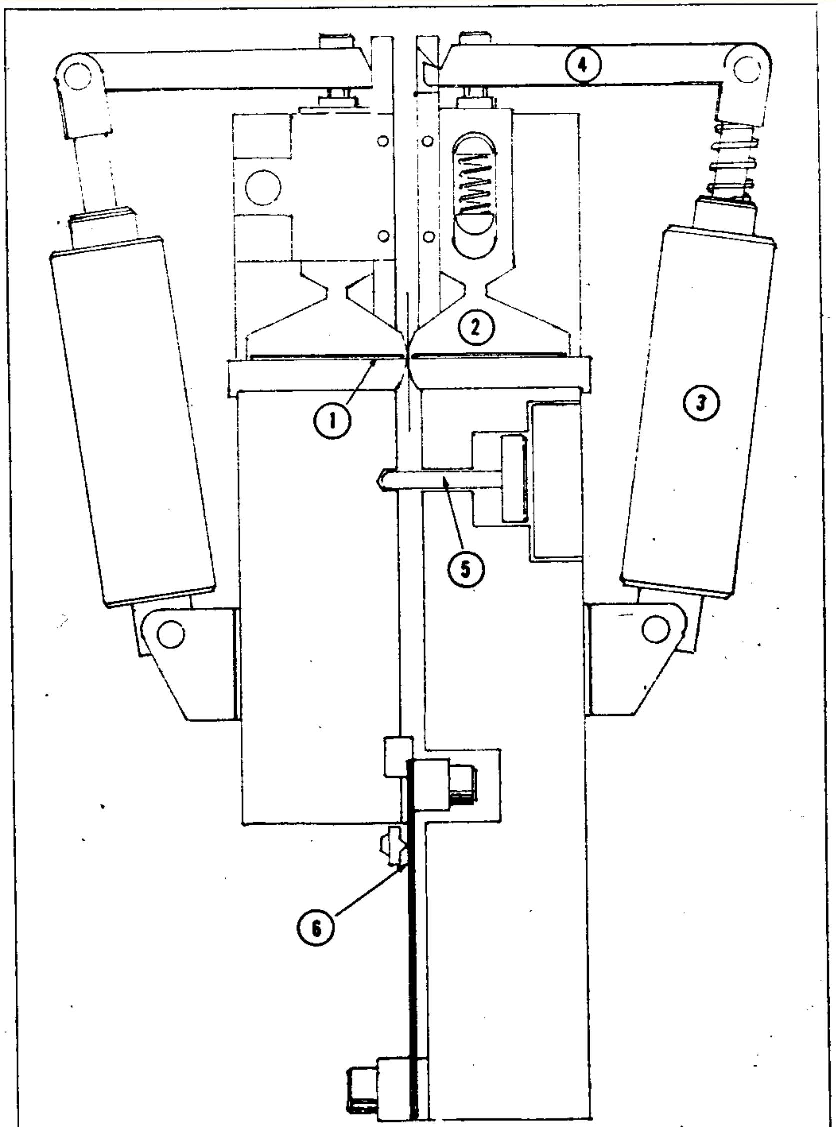

FIG. 5. Pulmac Zero Span Tester, schematic.

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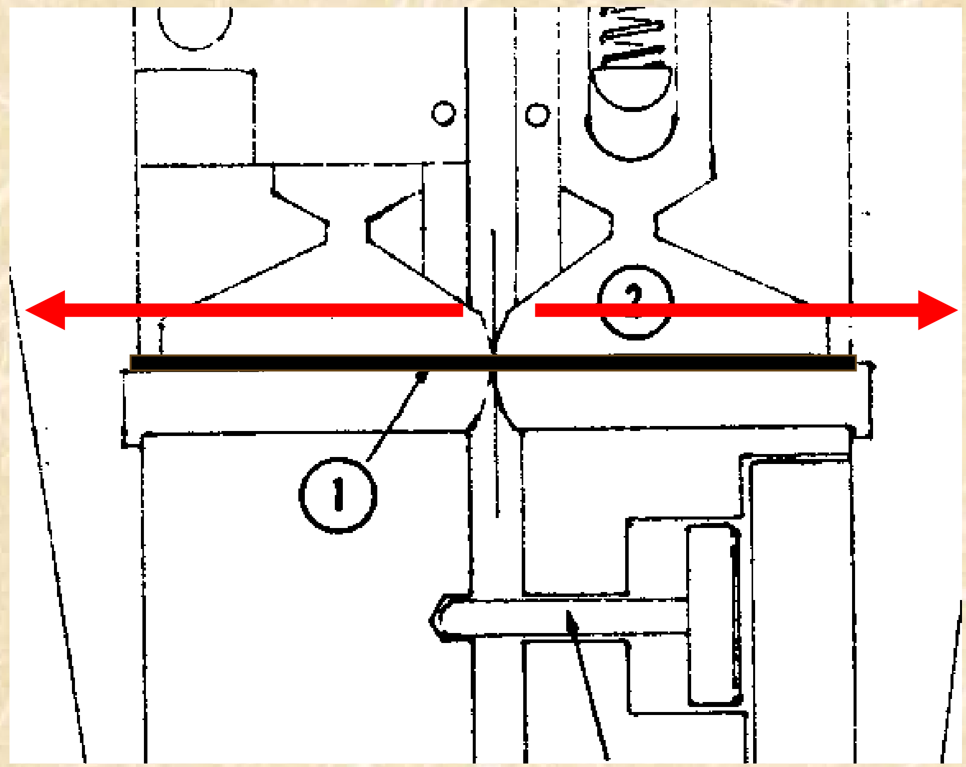


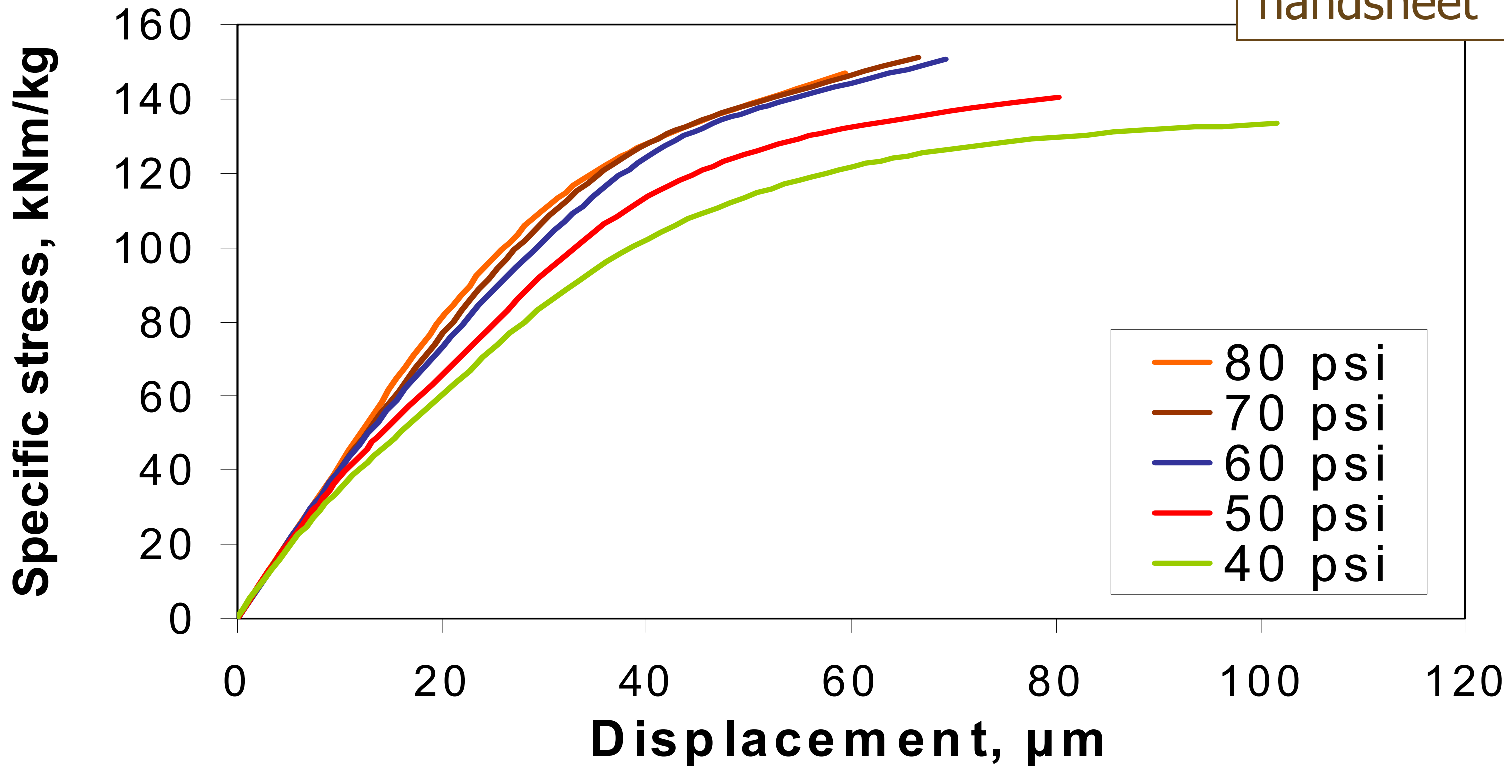
Recent research-what are we measuring?

- Two instruments measure force and displacement.
  - At SCA Graphic Research
- Pulmac Z span 2000
  - 24 tests at once- automatic feeder
  - Load controlled
  - Limited span, sample grammage
  - Displacement: Kaman contactless displacement transducer
  - Force: from pressure transducer in instrument.
- MTS 4/ML
  - Special grips+ conventional tensile tester
  - One test at a time- much slower
  - Large span, grammage range

Effect of Pressure- zero span test- Pulmac tests

- Fall in zero-span strength at low pressure due to slippage under jaws

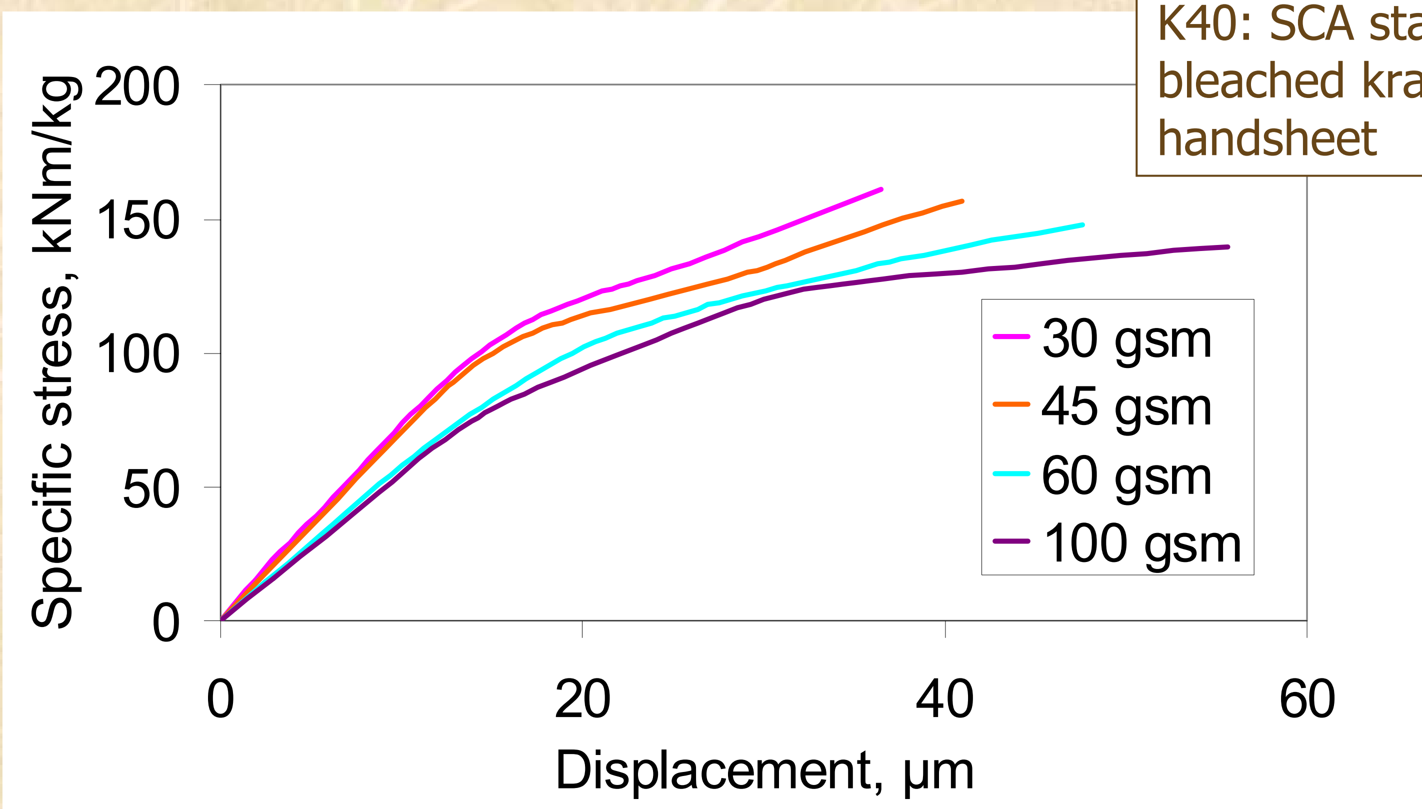
K40: SCA standard bleached kraft handsheet



Effect of grammage: zero-span load-displacement- Pulmac tests

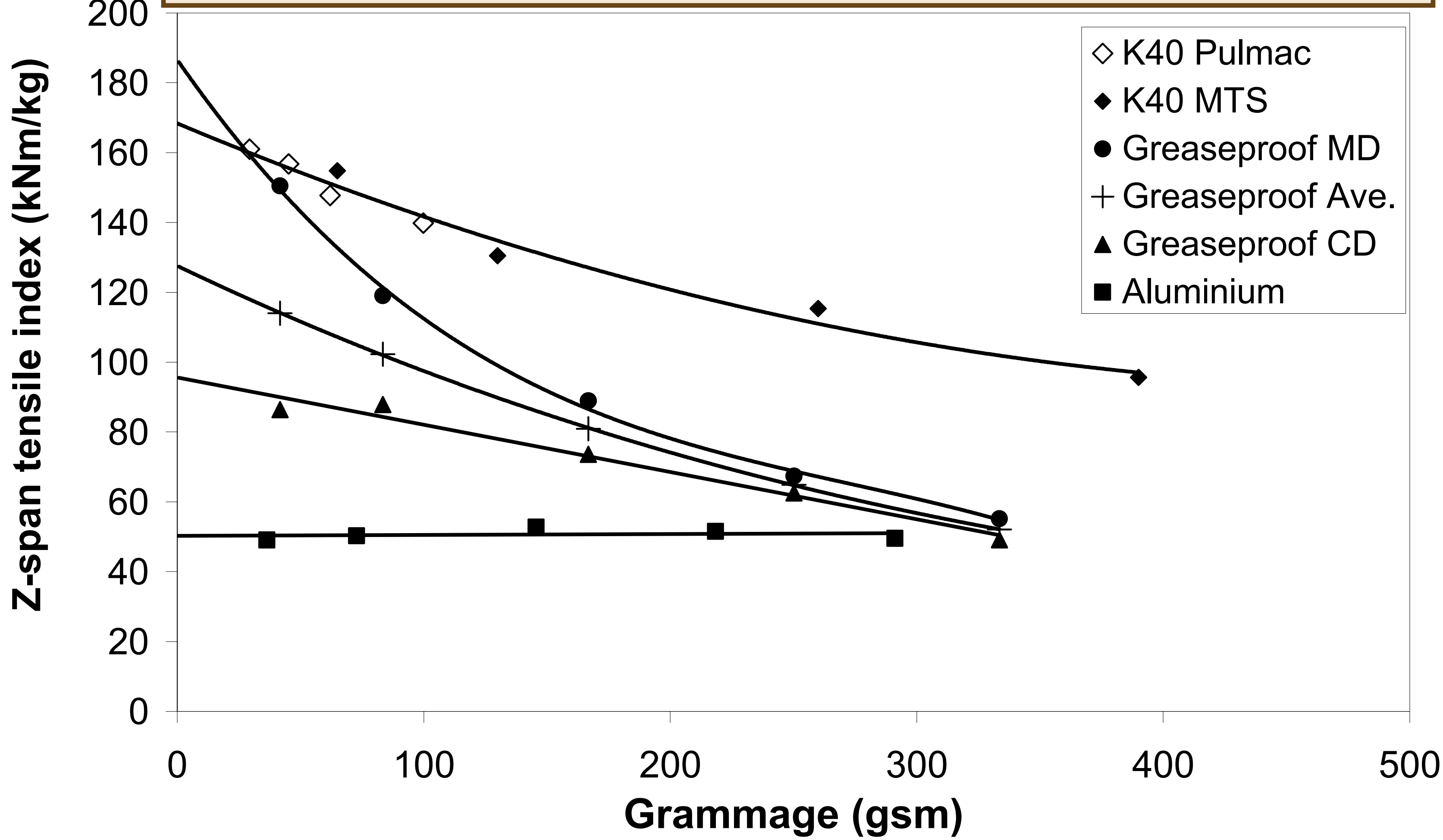
- Increasing grammage: large increase in displacement+ some reduction in zero-span strength

K40: SCA standard bleached kraft handsheet



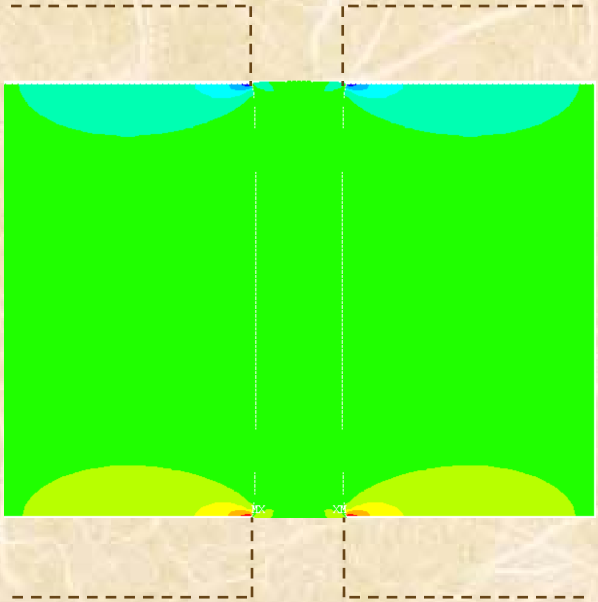
Intrinsic zero-span strength

Y-axis intercept= intrinsic zero-span strength

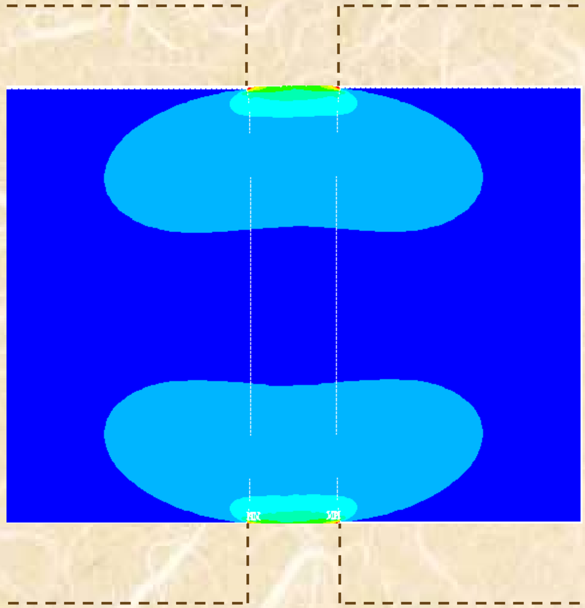


Stress transfer under jaws

Shear stress

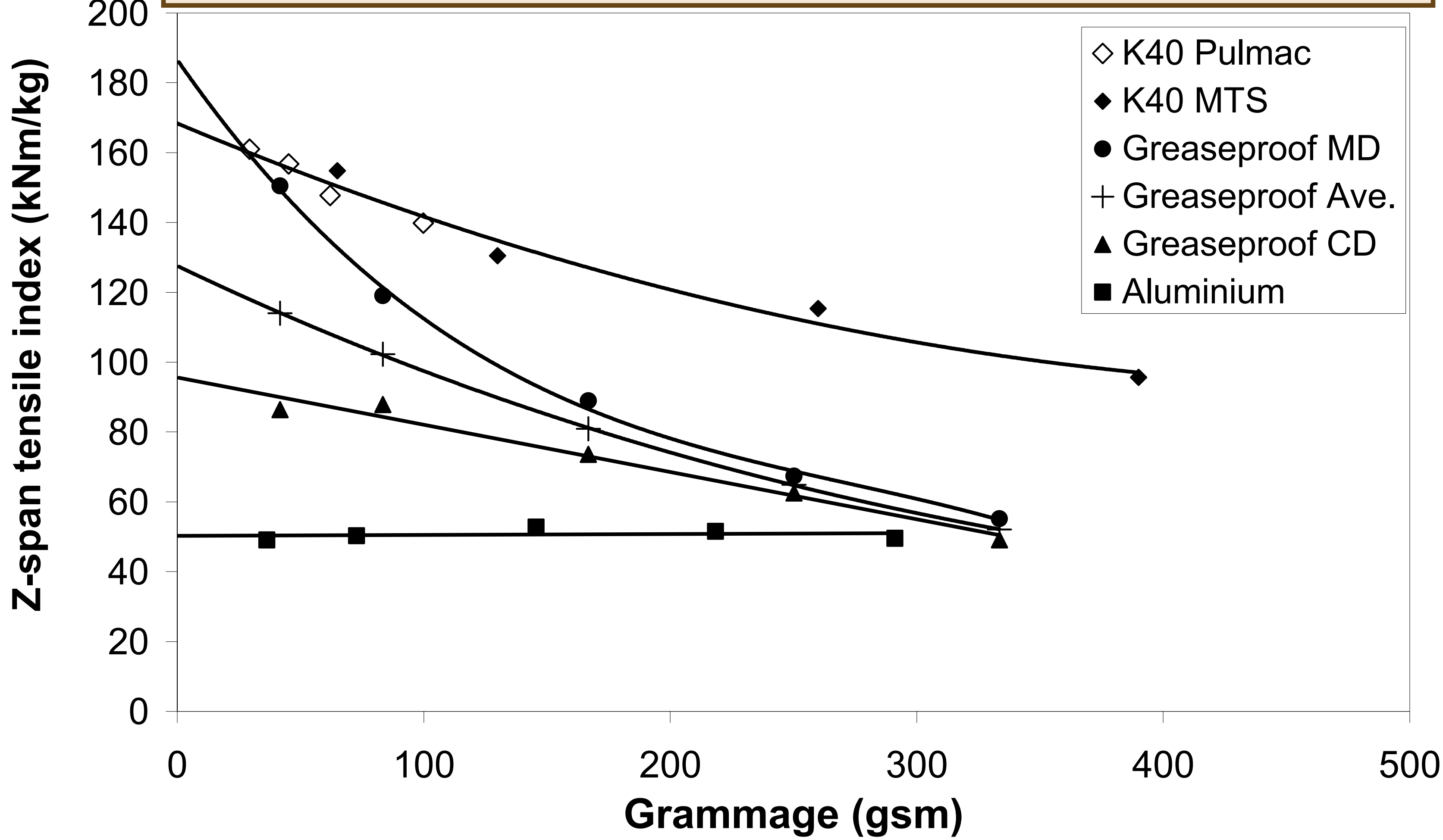


Normal stress in the loading direction



Intrinsic zero-span strength

Y-axis intercept= intrinsic zero-span strength



Recommendations for zero-span testing

- High enough pressure
- Y-axis intercept of strength v. grammage= intrinsic zero-span strength
- Paper: measured zero-span strength always less than intrinsic strength
  - Cause: non-uniform stress field under jaw, fibre-fibre stress transfer effects
  - Least accurate: high grammage, testing in MD direction.
  - Most accurate: low grammage, geometric mean of MD and CD

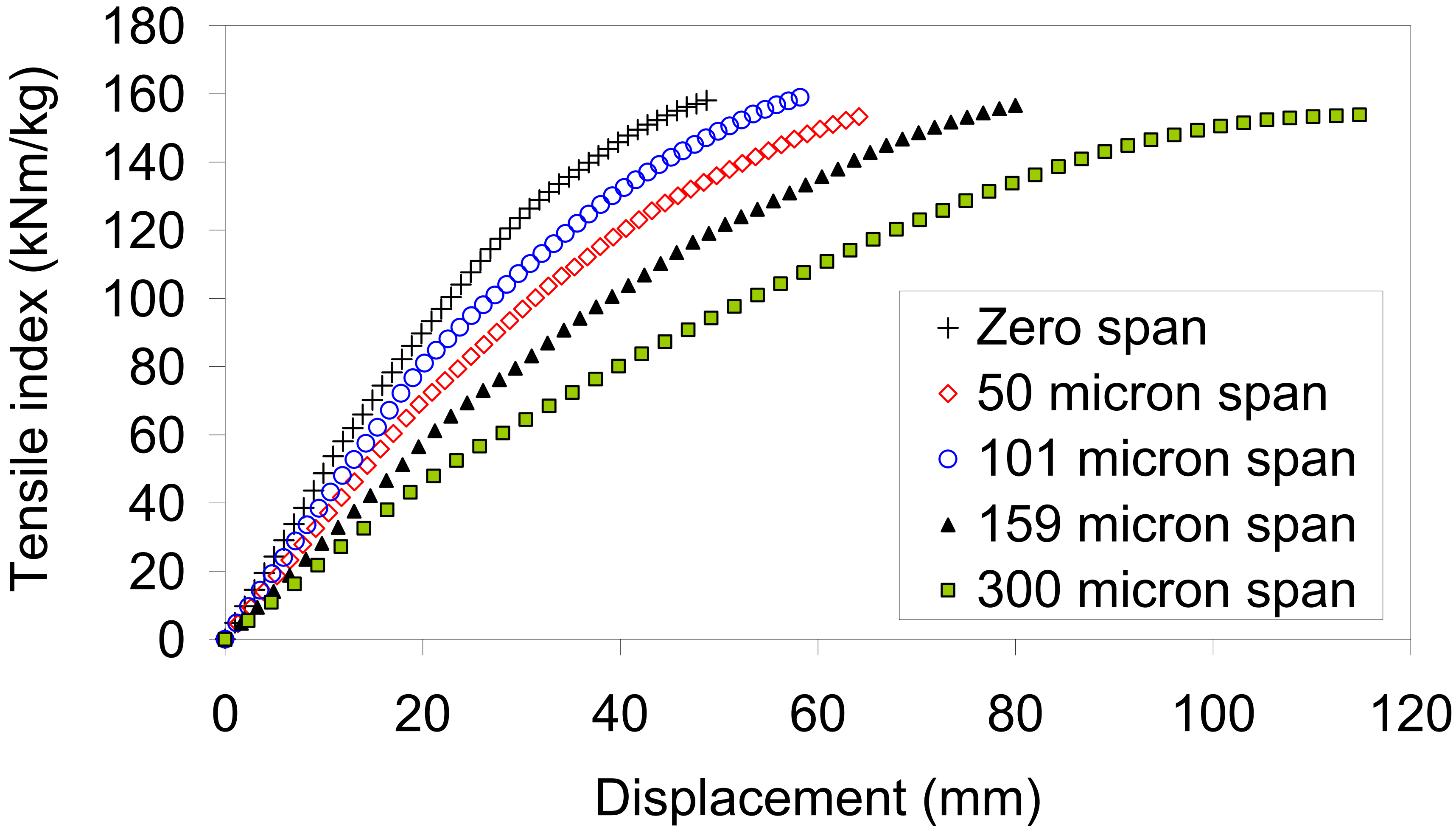
Recommendations for zero-span testing

- Test **dry** not wet
  - Fibre strength reduced, fibre stretch increases with moisture- fibres pull out when wet
  - State of dry fibres same as sheet in use
- Fibres pull-out in test?
  - Wrong result- fibres haven't broken
  - Can check fracture line
  - Bonding better
  - Longer fibres better

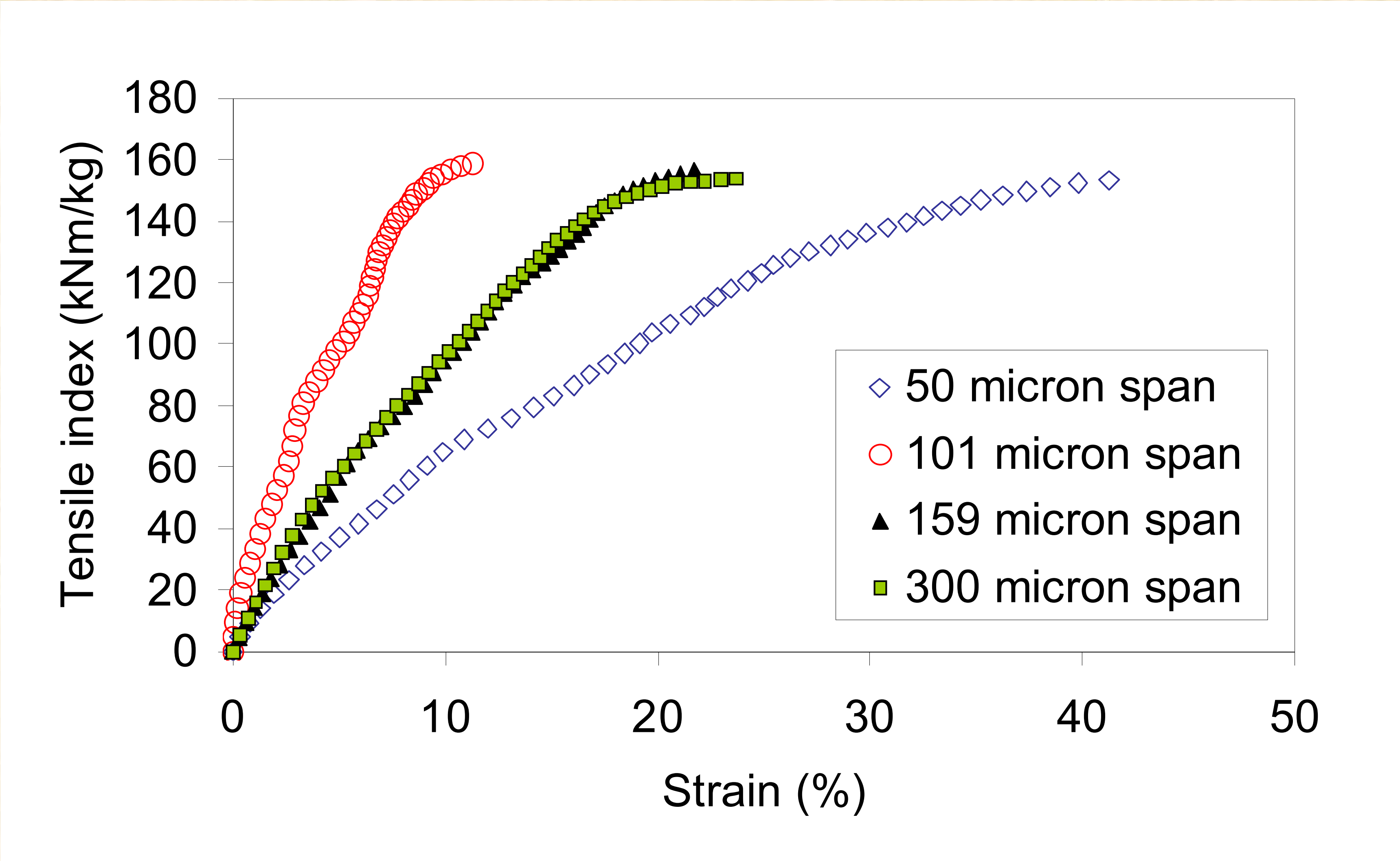
Subtraction method

- Goal: measure “average” fibre modulus and breaking strain from zero and short span tests
- Measure load-displacement for multiple tests
  - Remove load, take up, initial span
  - Calculate average curve
- Subtract zero-span curve from short-span curve
  - Load-displacement from short span only
  - Divide by span to get stress-strain
  - Independent of bonding
- Next two slides: freely dried unbleached Swedish kraft

Load-displacement data

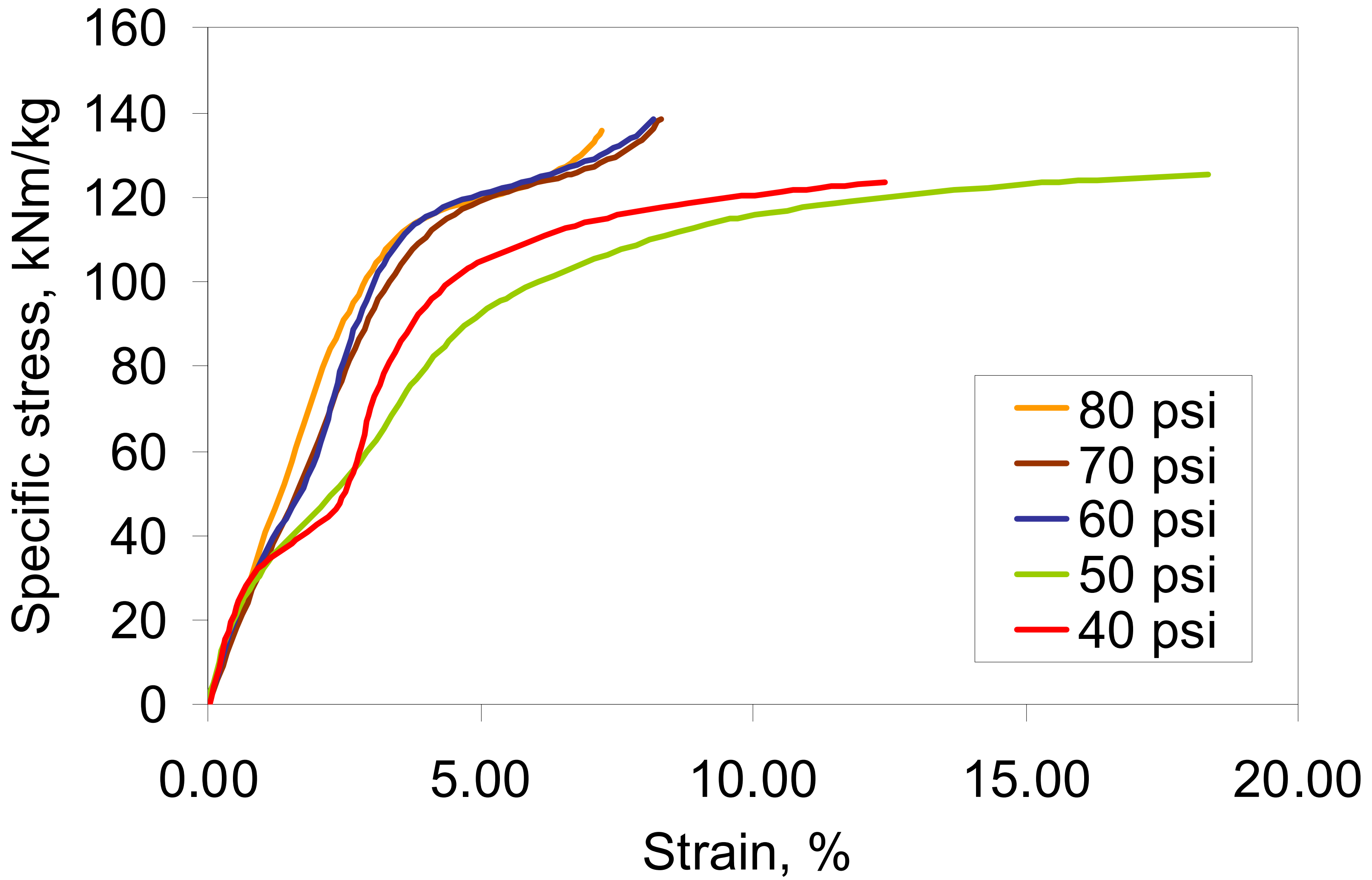


Subtracted curves

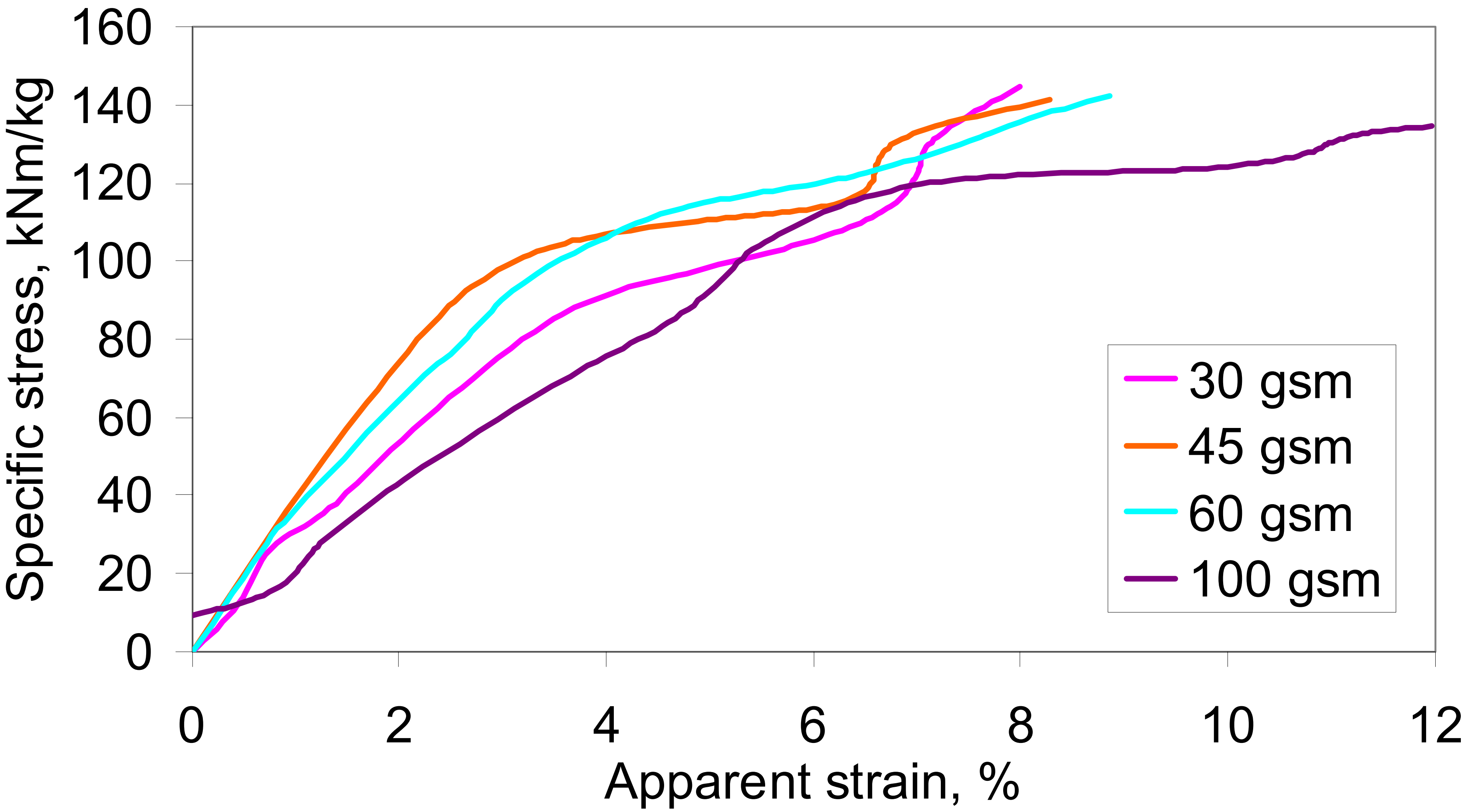


Subtraction most accurate: longer spans.

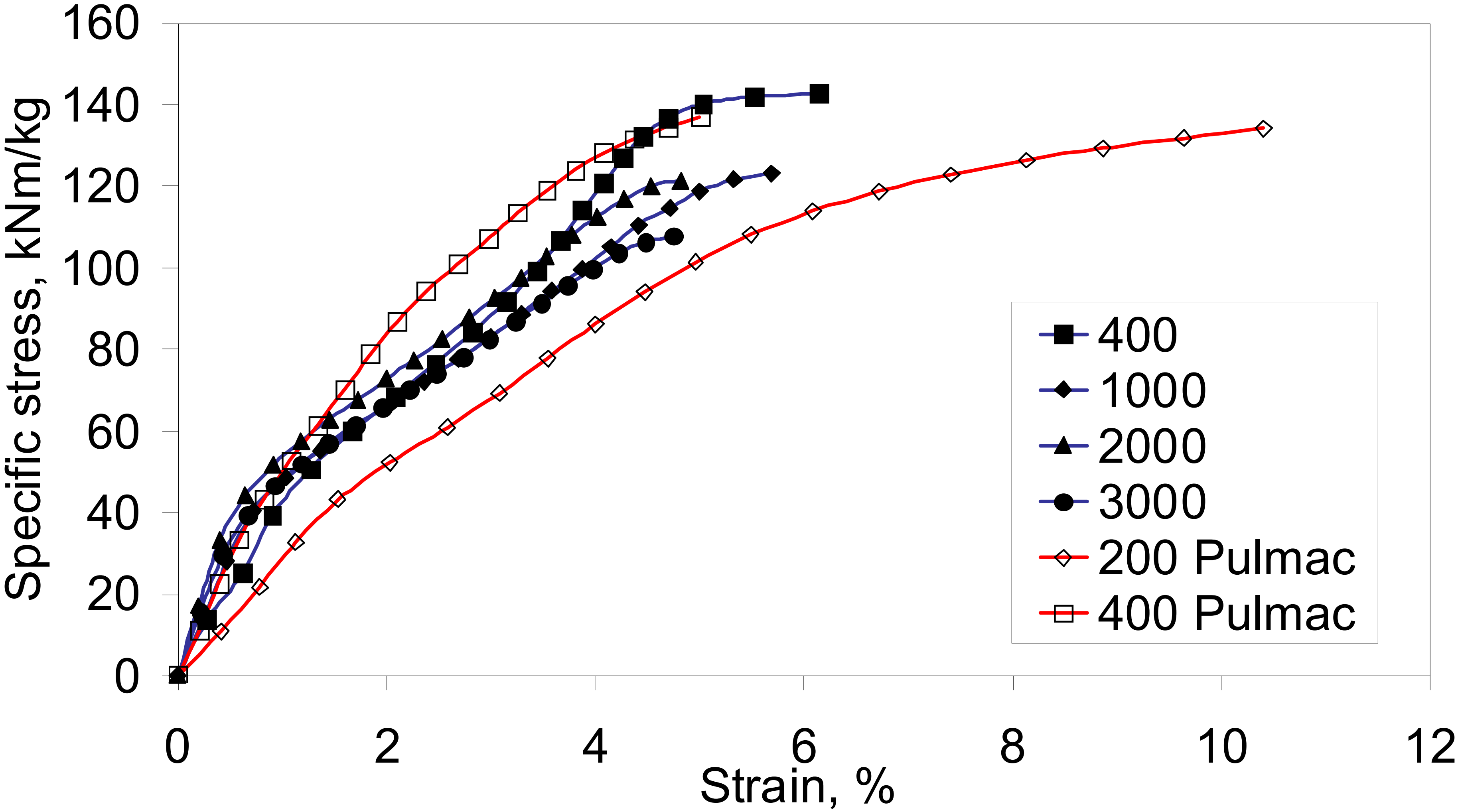
Subtraction technique: K40-effect of pressure



K40- Effect of grammage



K40- effect of span



Comparison of zero-span with single fibre data

- Van den Akker: Z-span strength: 3/8 of strength all fibres in test direction.
  - Isotropic sheet
- Assume fibre density=1500 kg/m^3 then

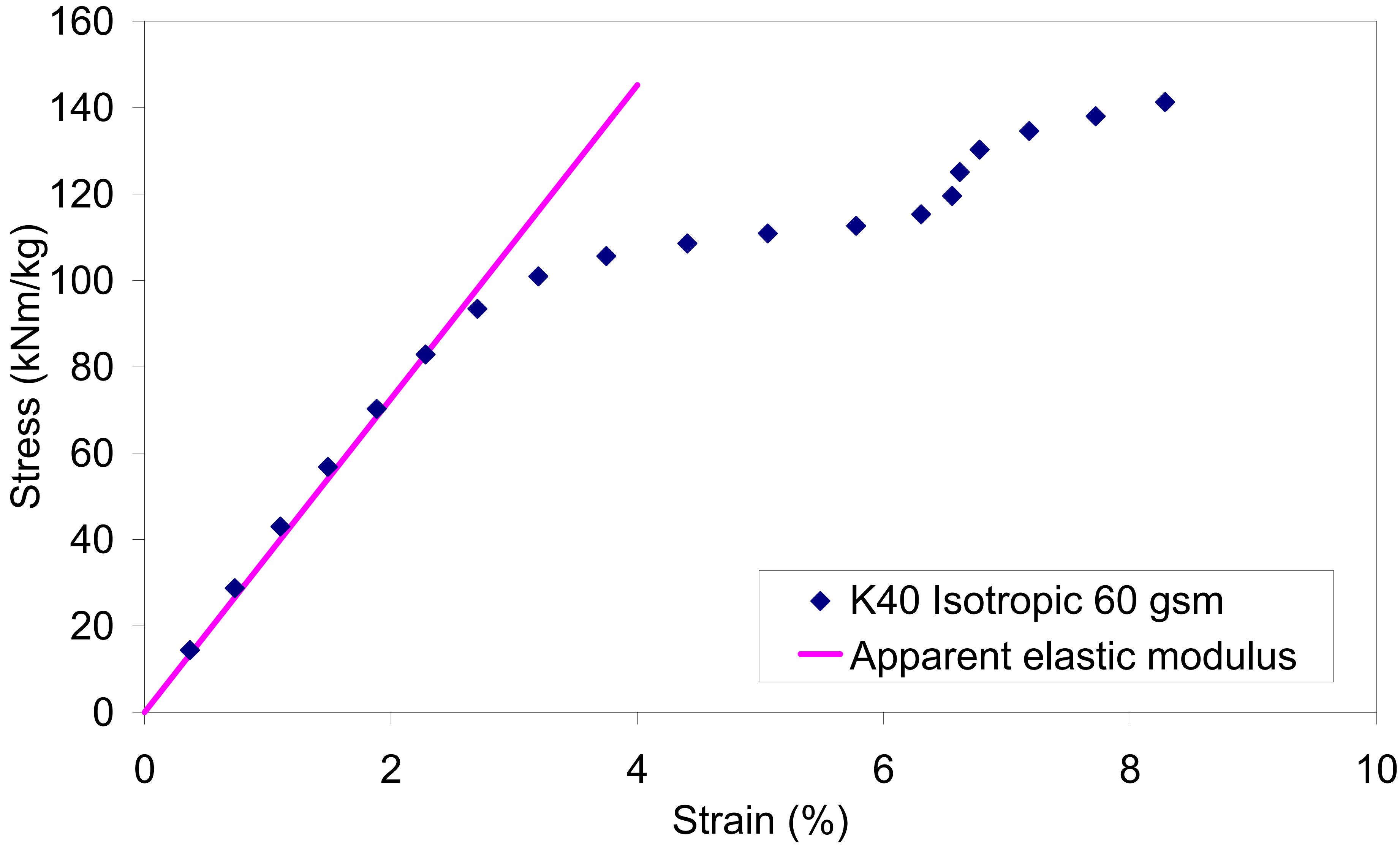
$$\sigma_f = 4Z$$

σ_f : Fibre breaking stress (MPa)

Z: Zero span tensile index (kNm/kg)

- Next slides
- K40 handsheets
- Compared with literature data
  - Experiments by Page and co-workers from 1970s.

The data



160
140
120
100
80
60
40
20
0
Stress (kNm/kg)
0
2
4
6
8
10
Strain (%)
K40 Isotropic 60 gsm
Apparent elastic modulus

Comparison of zero span strength with single fibre strength

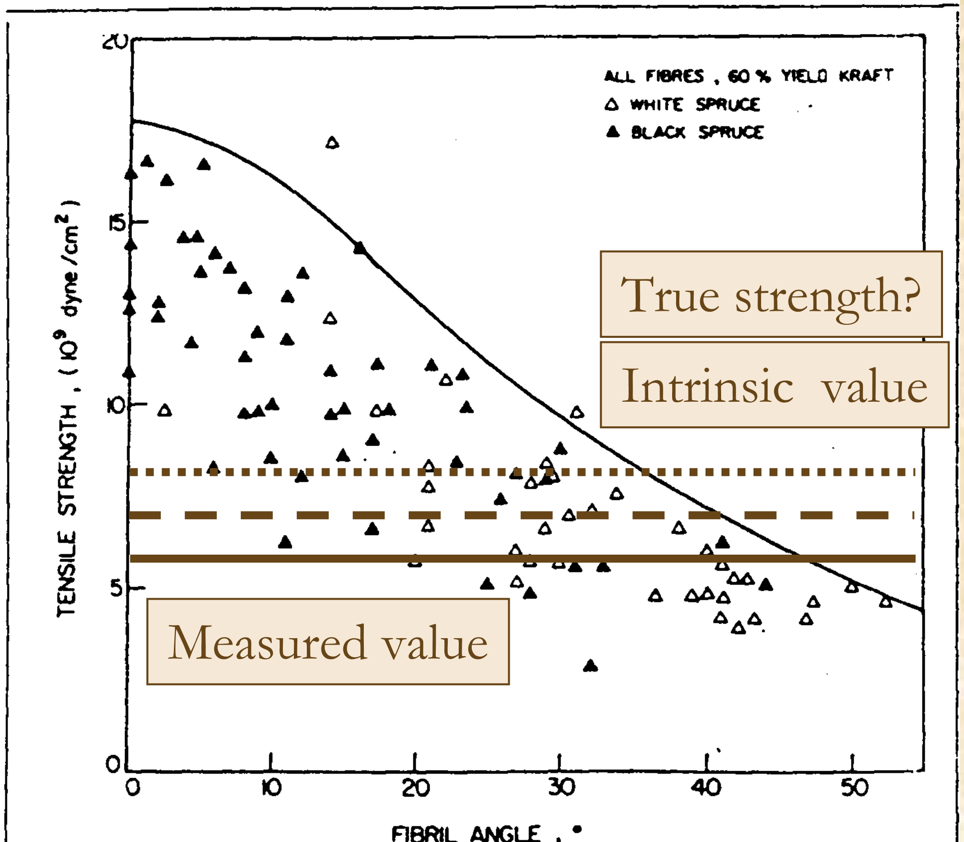


FIG. 4. Tensile strength-fibril angle plot for all fibres of black and white spruce. The line is derived from Hill's criterion of failure and is fitted to the upper bound of strength.

Taken from Page et al (1972)

Breaking strain

- Breaking strain range quite large for same material.
  - Uncertainties in subtraction technique.
  - Can't directly compare same sample for subtraction

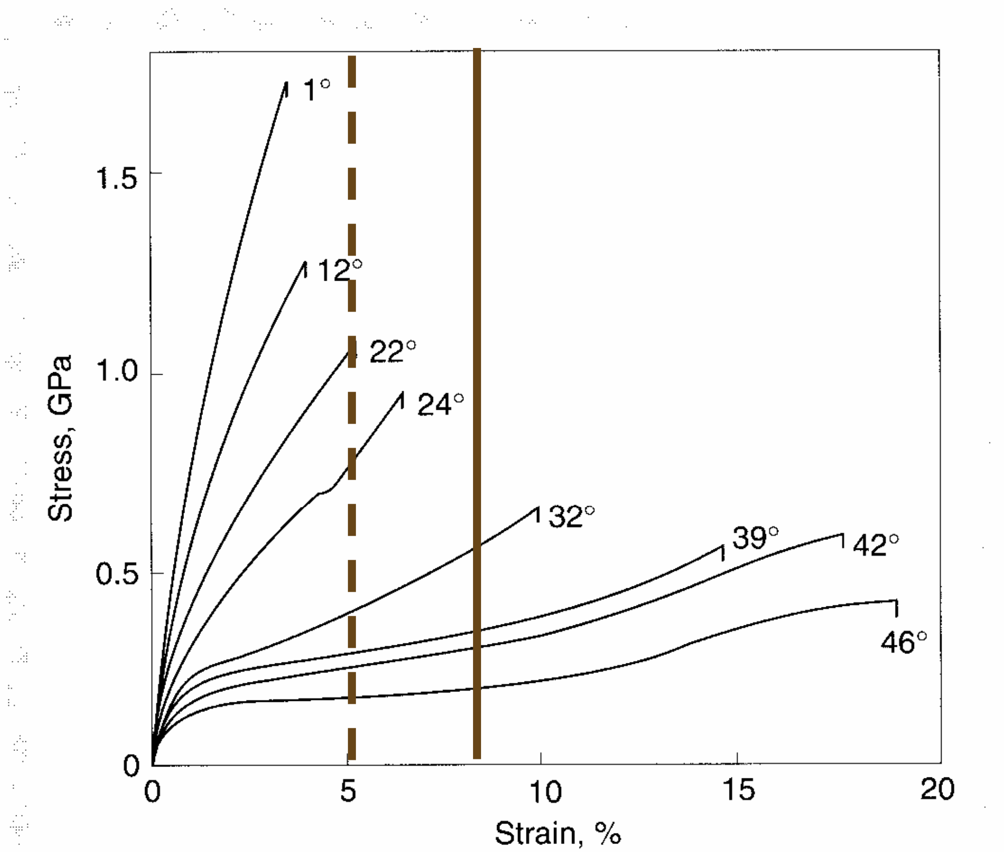
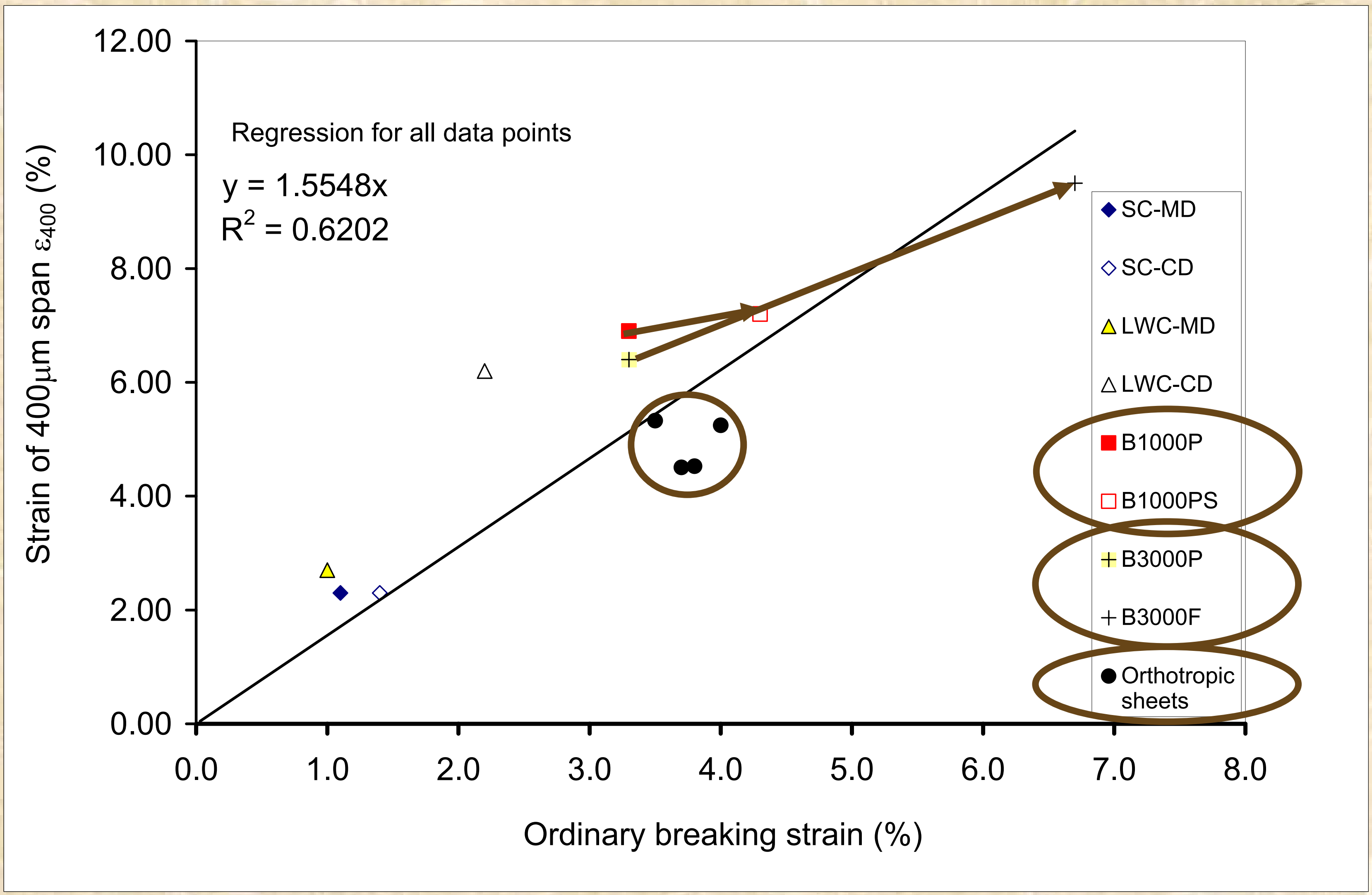


Figure 11. Load-elongation curves for black spruce fibers (45% yield kraft) with different fibril angle, measured using 1.2 mm span[20].

Graph from Niskanen, editor, "Paper Physics"

Relationship between fibre breaking strain from subtraction and ordinary breaking strain



Comparison with Single fibre elastic modulus data.

- Calculated elastic modulus too low.
- Probably due to uneven stress distribution under jaws.

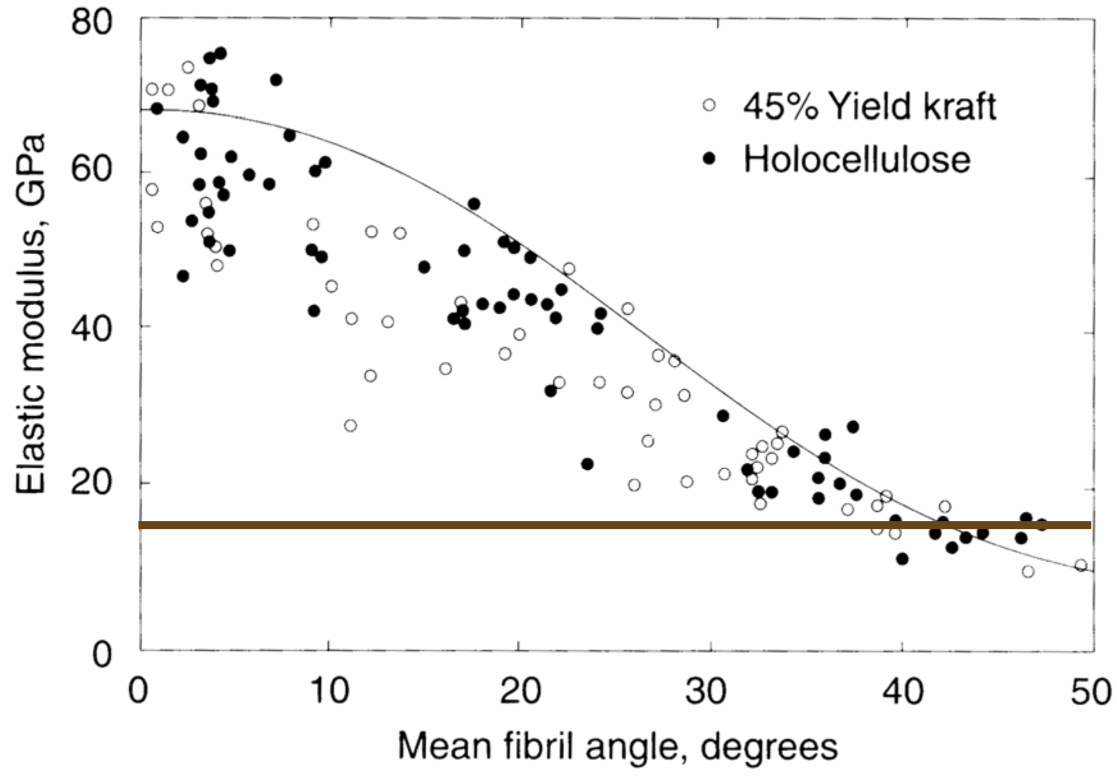


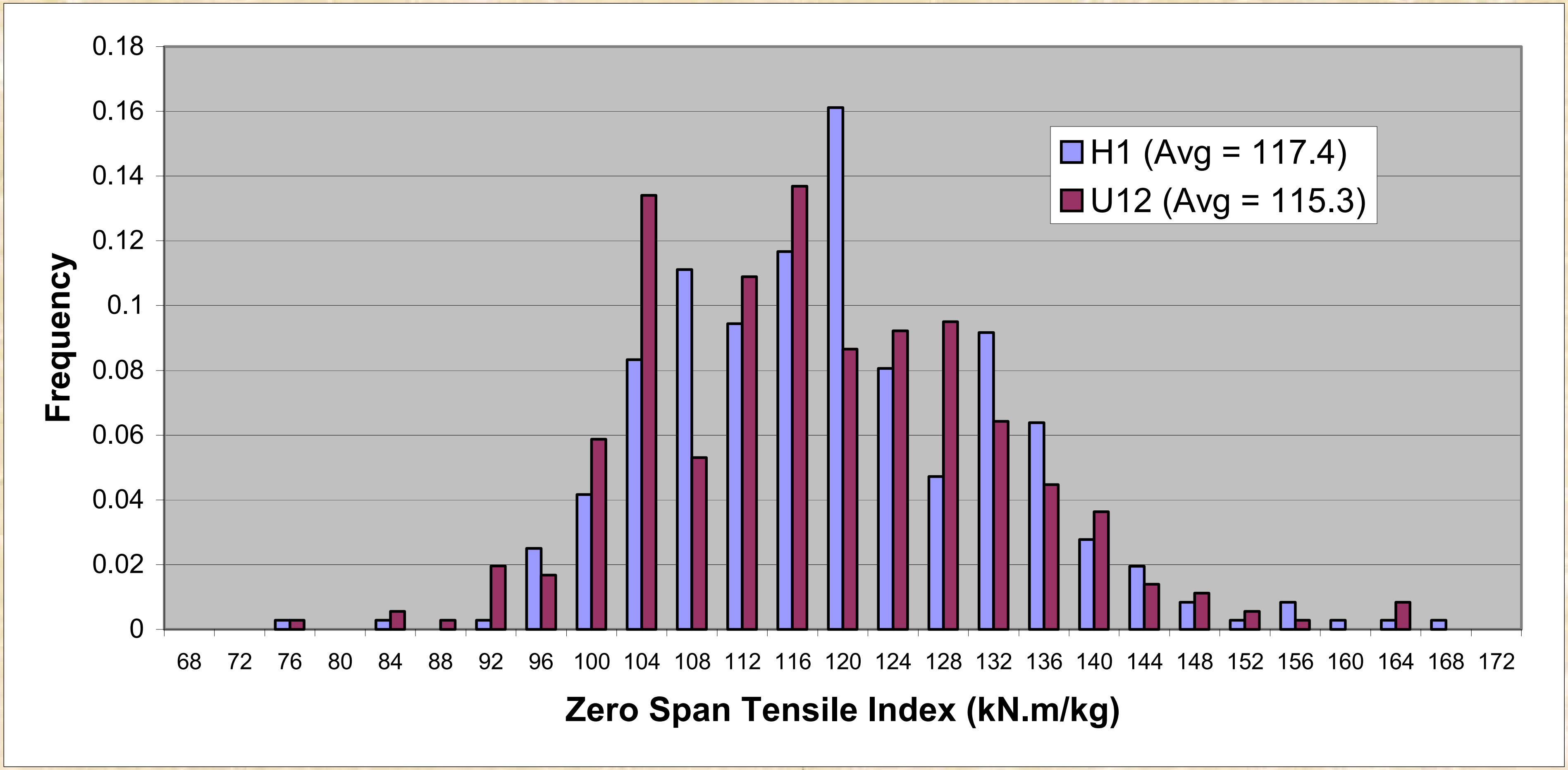
Figure 12. Elastic modulus of fibers vs. the fibril mean angle of the S2 layer. The solid line gives a theoretical prediction[26].

Taken from Niskanen, Paper Physics (1998)

Conclusions: subtraction technique and single fibre comparison

- Curve from subtraction independent of test conditions IF
  - High clamping pressure
  - Standard handsheet grammage or less
  - Span greater than 400μm or more is used for subtraction
- Comparisons with single fibre data
  - Remember the factor of 4!
  - Single fibre strength: Comparable ☺
  - Single fibre breaking stretch: Comparable ☺
  - Elastic modulus: Far too low ☹

Other issues: zero span strength distributions



What is the Z-strength where paper fractures?

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