The Zero-Span test-
What are we measuring?

Warren Batchelor
Australian Pulp and Paper Institute
Monash University
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.

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.
Zero-span measurements

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• Cons
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    • Stress transfer from jaw
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    • Stretch and modulus?
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  – Average only
  – Affected by fibre defects
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

Grammage (gsm)

Z-span tensile index (kNm/kg)

- K40 Pulmac
- K40 MTS
- Greaseproof MD
- Greaseproof Ave.
- Greaseproof CD
- Aluminium
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

![Graph showing load-displacement data for different spans. The y-axis represents Tensile index (kNm/kg) and the x-axis represents Displacement (mm). The graph includes markers for Zero span, 50 micron span, 101 micron span, 159 micron span, and 300 micron span.]
Subtracted curves

Subtraction most accurate: longer spans.
Subtraction technique: K40-effect of pressure

![Graph showing the effect of pressure on specific stress and strain.](image-url)
K40- Effect of grammage

![Graph showing the effect of grammage on specific stress and apparent strain.](image)

- Specific stress, kNm/kg
- Apparent strain, %

- 30 gsm
- 45 gsm
- 60 gsm
- 100 gsm
K40- effect of span

![Graph showing effect of span on specific stress vs strain. The graph plots specific stress in kN/m²/kg on the y-axis against strain in % on the x-axis. Lines represent different values of span, with 400, 1000, 2000, 3000, and 200 Pulmac and 400 Pulmac. The graph illustrates the relationship between span and stress-strain behavior.]
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/m³ then

\[ \sigma_f = 4Z \]

\( \sigma_f \) : 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

- Zero-span tensile index: 142 kNm/kg
- Apparent elastic modulus: 3600 kNm/kg
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. Graph from Niskanen, editor, “Paper Physics”
Relationship between fibre breaking strain from subtraction and ordinary breaking strain

Regression for all data points

\[ y = 1.5548x \]

\[ R^2 = 0.6202 \]
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\textsuperscript{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

![Graph showing zero span tensile index distributions for H1 and U12 samples.]

What is the Z-strength where paper fractures?
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