Measurement of Fibre Stress-Strain Properties with Zero/Short-Span Testing

Warren Batchelor[1] and Bo Westerlind[2]

[1]Australian Pulp and Paper Institute, Dept of Chemical Engineering, Monash University, Australia

[2]SCA Research, Sundsvall, Sweden

Introduction

- Stress-strain behaviour of fibres- large factor in sheet mechanical properties
- Measurement?
  - Single fibre tests?
    - Many tests
    - Representative of fibres in sheet?
  - Zero span test
    - Tensile test at zero span- no gap between jaws
    - Measure of mechanical properties of fibres in the sheet
    - Normally only measure breaking load

Our work

- Goal: measure stress-strain properties of fibres in sheet
- Method: Pulmac zero/short span tester with additional instrumentation.
  - Kaman Corp. capacative transducer- measure jaw separation
  - Continuous measurement of load during test.
  - Thus can measure load-displacement during test
  - Need method to convert displacement to strain.
- Each curve average of 24 tests

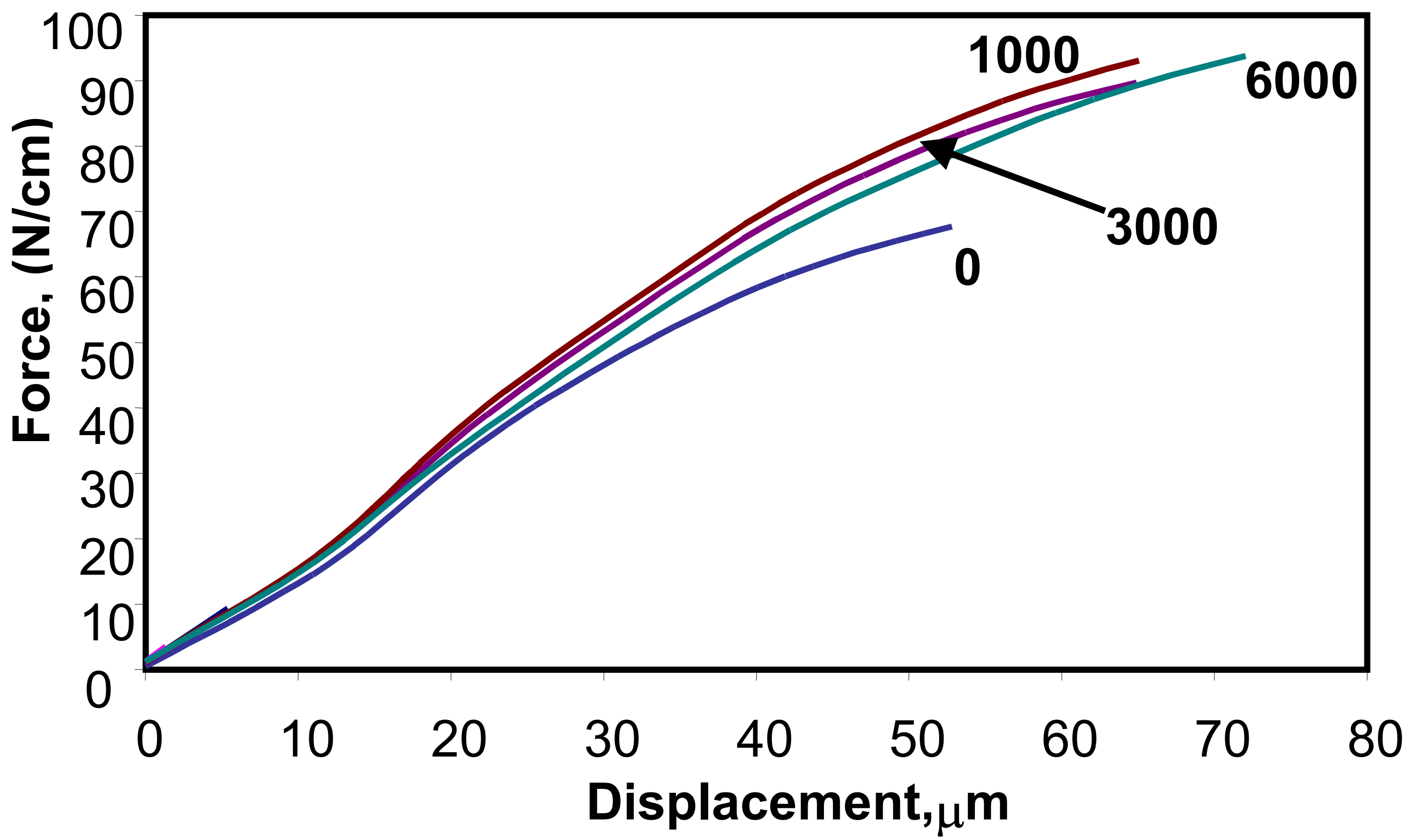
Experimental- pulps

- A: Never dried unbleached kraft (SCA's Östrand mill)
- B: Never dried bleached kraft (SCA's Östrand mill)
- C: Once dried bleached kraft
  - Free dried from pulp B:, reslushed and formed into handsheets
- D: TMP, 120ml CSF, (SCA's Ortviken mill)
- E: TMP, 54ml CSF, (SCA's Ortviken mill)

Measurements

- Sheets formed by teflon drying with heated drum
  - Low level of restraint
- PFI refining: 1000, 3000 and 6000 revs (for pulps A,B,C)
- Zero/short span measurements
  - 0, 50, 100, 150 and 300 micron spans
  - Tests conducted dry
- Standard laboratory tests for strength, fibre length etc.

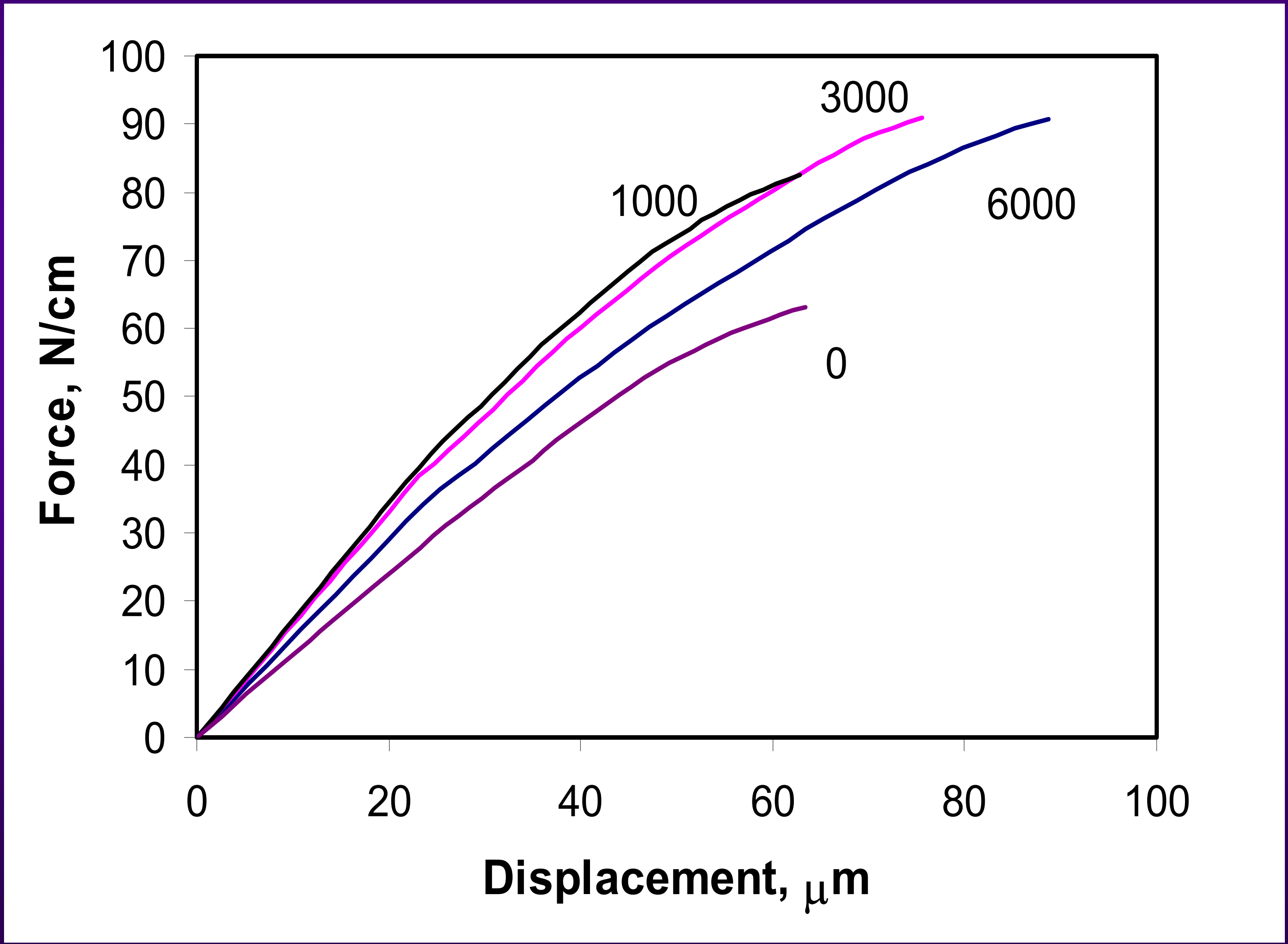
‘Raw’ Force-displacement curves for a bleached kraft pulp (B) for different refining levels (PFI revolutions)



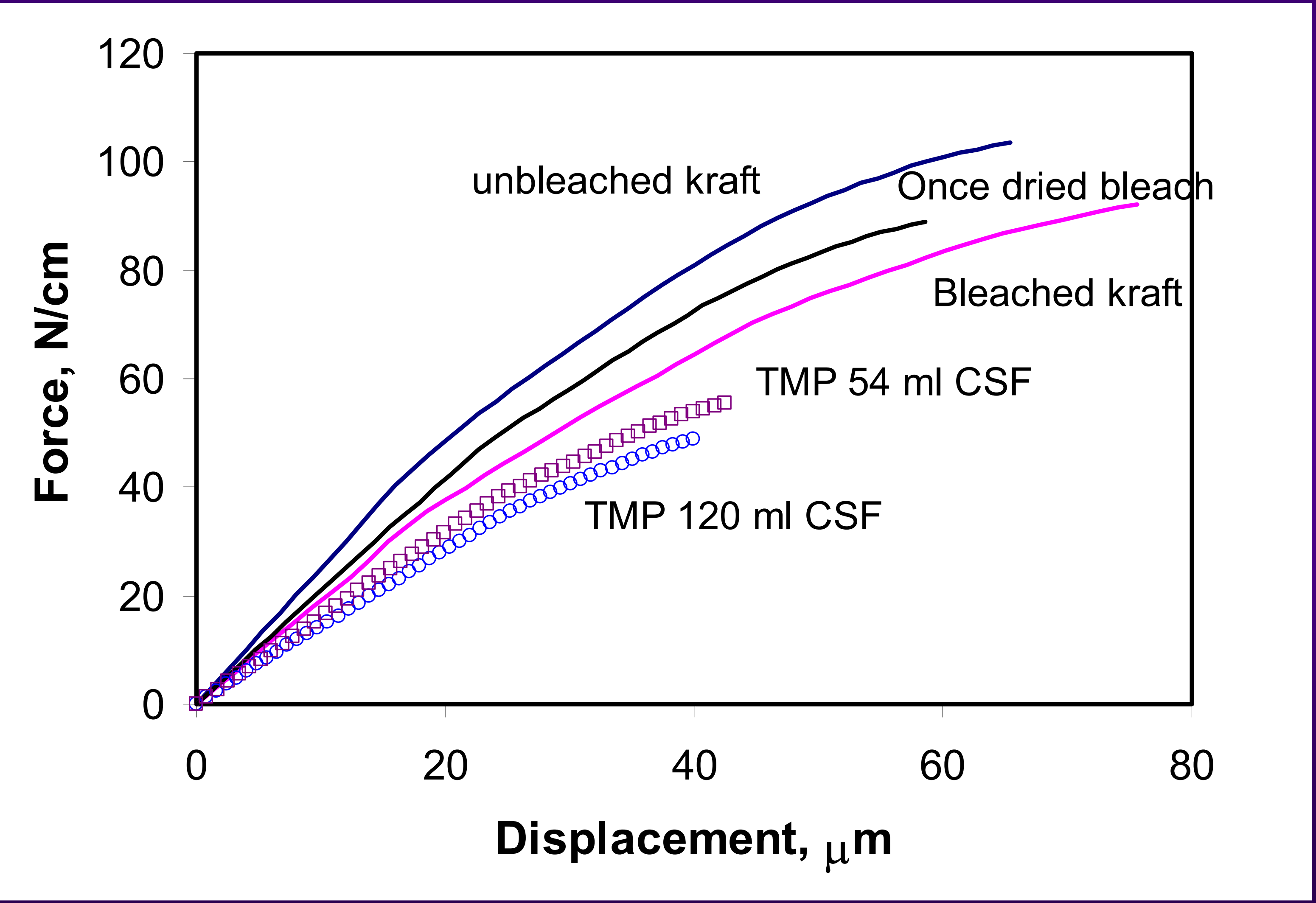
Problem: Where is test start point?

- Load take up effects at start of test
  - Dependent on level of drying restraint
- Solution used:
  - Determine point of maximum slope of curve
  - Extrapolate gradient to determine displacement at 0 N force
  - Subtract extrapolated displacement from measured

Effect of PFI refining (revs) on bleached kraft pulp (B). Curves corrected to remove load take up effects



Force-displacement curves for five pulps beaten to 3000 PFI revs

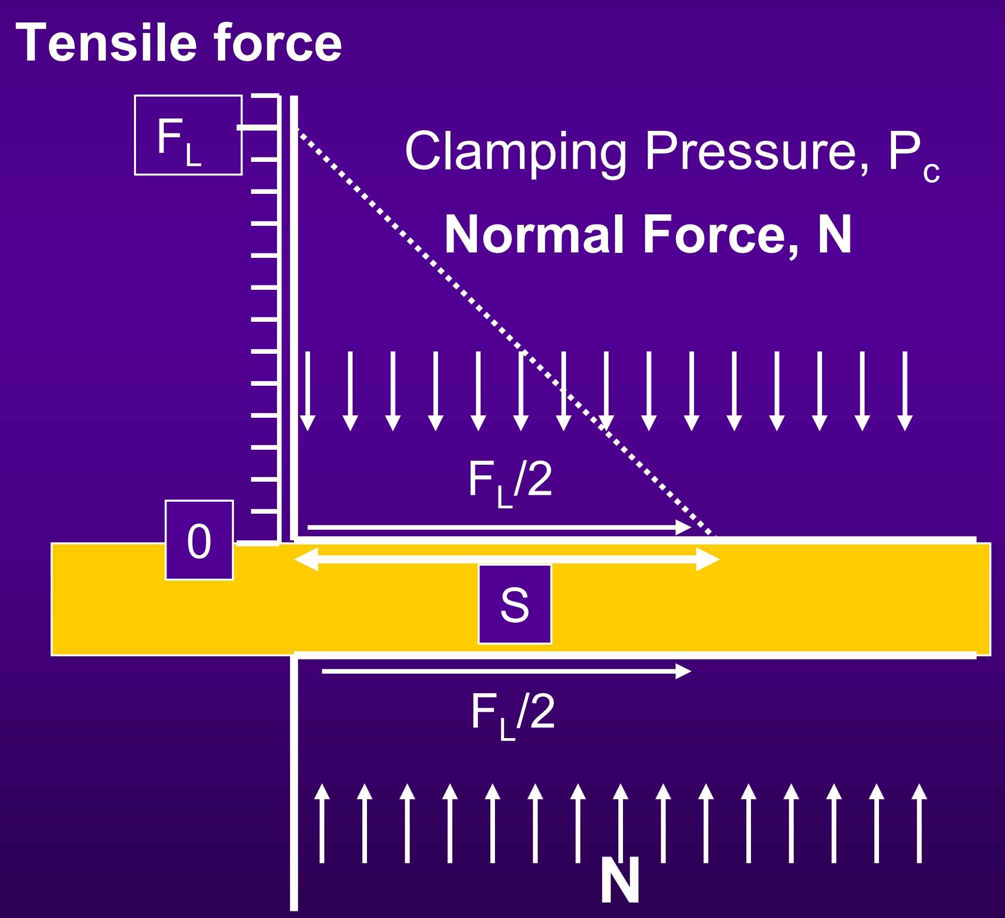


Residual span

- Fibres held in place by friction under the jaw clamping pressure.
- Requires a finite distance from jaw edge to work, and also depends on force at any point in the test.
- Residual span not known
- Need method to convert measured load-displacement to stress-strain.

Zero span test- theory

- Load on sample, F_L
- Applied by friction, at two jaws over distance, S
- Displacement during test comes from slippage under both jaws
- Span is $S = \dfrac{F_L}{2\mu P_c}$
- μ: coefficient of friction



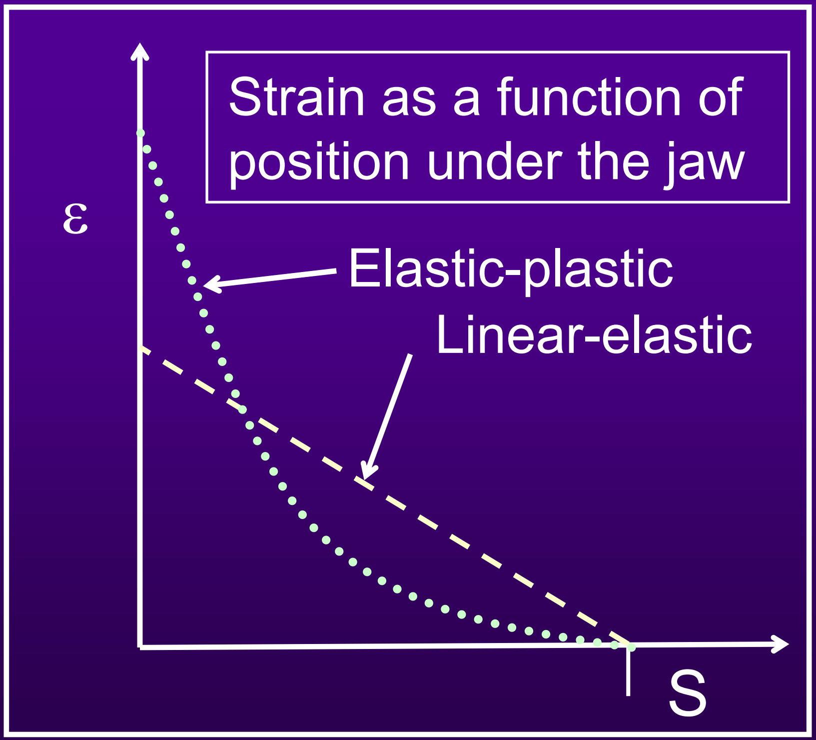
- **Linear-elastic behaviour**
  - Average strain is equivalent to load, F_L, applied over span, S
  - S is then the residual span

$$F_L = \left[\frac{\Delta G_j 2 \mu P_c}{E_p} \right]^{1/2}$$

ΔG_j : Jaw displacement

E_p : Paper elastic modulus

- **Non-linear**
  - Average strain depends on stress-strain curve
  - Concept of a residual span is then meaningless



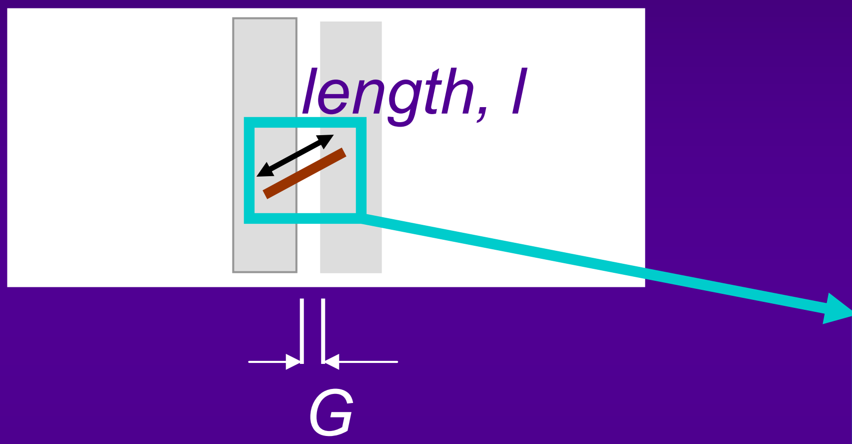
Non-linear behaviour

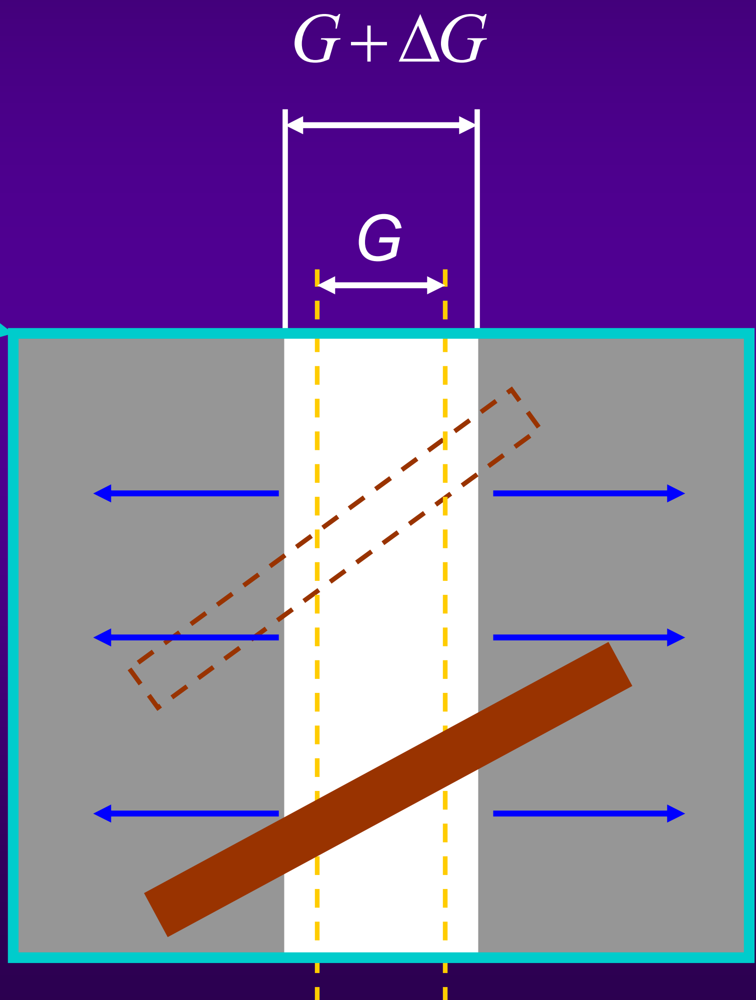
- Consider general case
  - Paper: stress-strain characterised by $\varepsilon = K(F)$
- Displacement is then given by (*x* is distance from jaw edge)

$$\Delta G_j = 2 \int_0^{F_L / 2uP_c} K(F(x))dx$$

- Problem: only determine stress-strain properties by knowing them in first place!

Short span test- theory





Overall strain: $$\varepsilon = \frac{\Delta G}{G}$$

Load-bearing element

- NOT a fibre
  - Fibres can be made up of many elements
  - Joined by kinks etc
- Properties:
  - Length, *l*
  - Cross sectional area, *C*
  - Young's modulus, *E*

Short span theory

$$F_L = E_p\left[1 - c\frac{32}{9\pi}\frac{G}{\overline{l(0)}}\right]\frac{\Delta G}{G}$$

F_{L} force (measured)

E_p paper elastic modulus at very small span

G test span

$\overline{l(0)}$ average load - bearing element length

ΔG displacement from straining span of G

c $= 1$, unbonded

≈ 0, long fibres, perfectly bonded

Assumptions

1) $G < 0.7\,\overline{l(0)}$

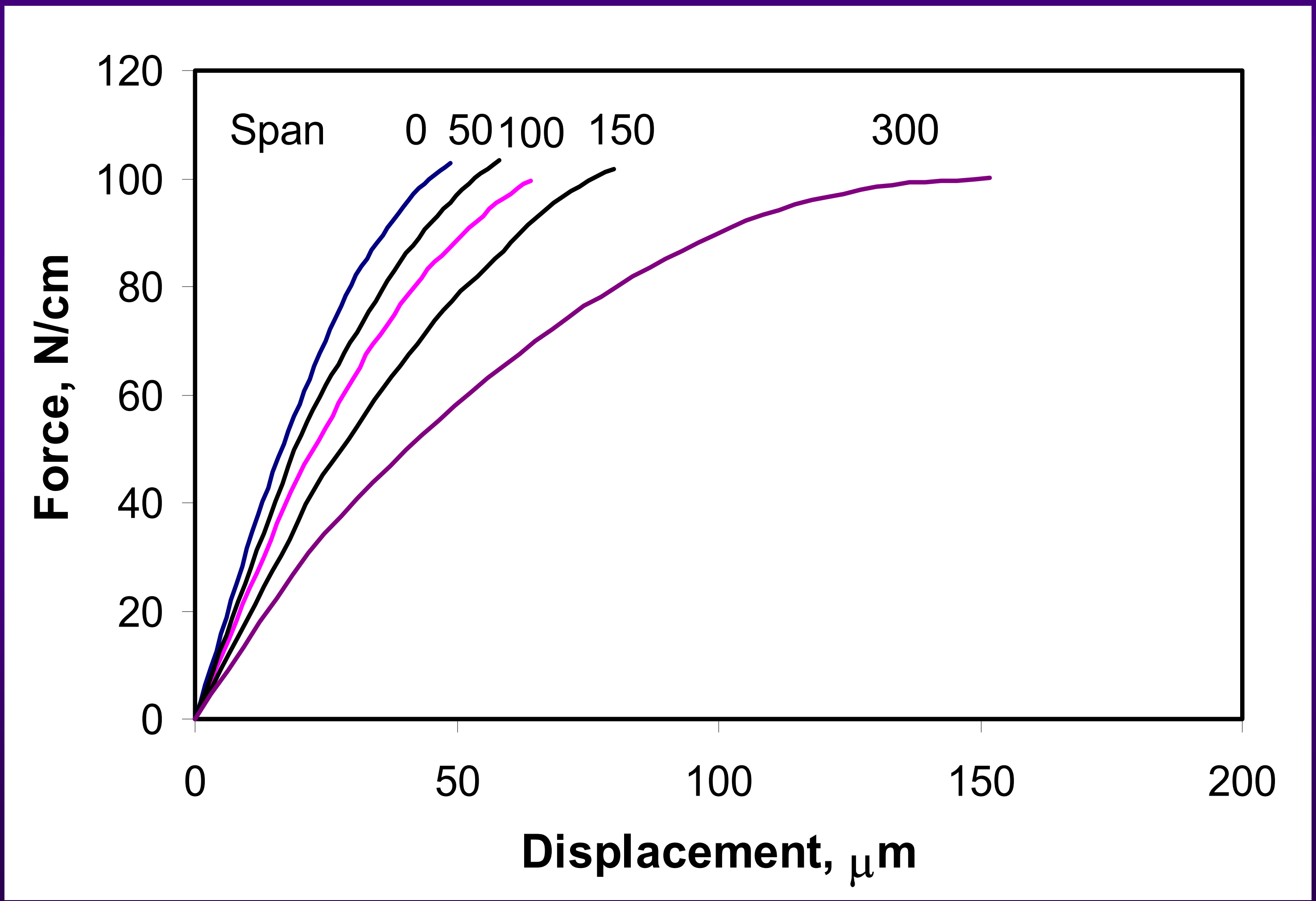
2) Random orientation

3) All fibres crossing both jawlines contribute

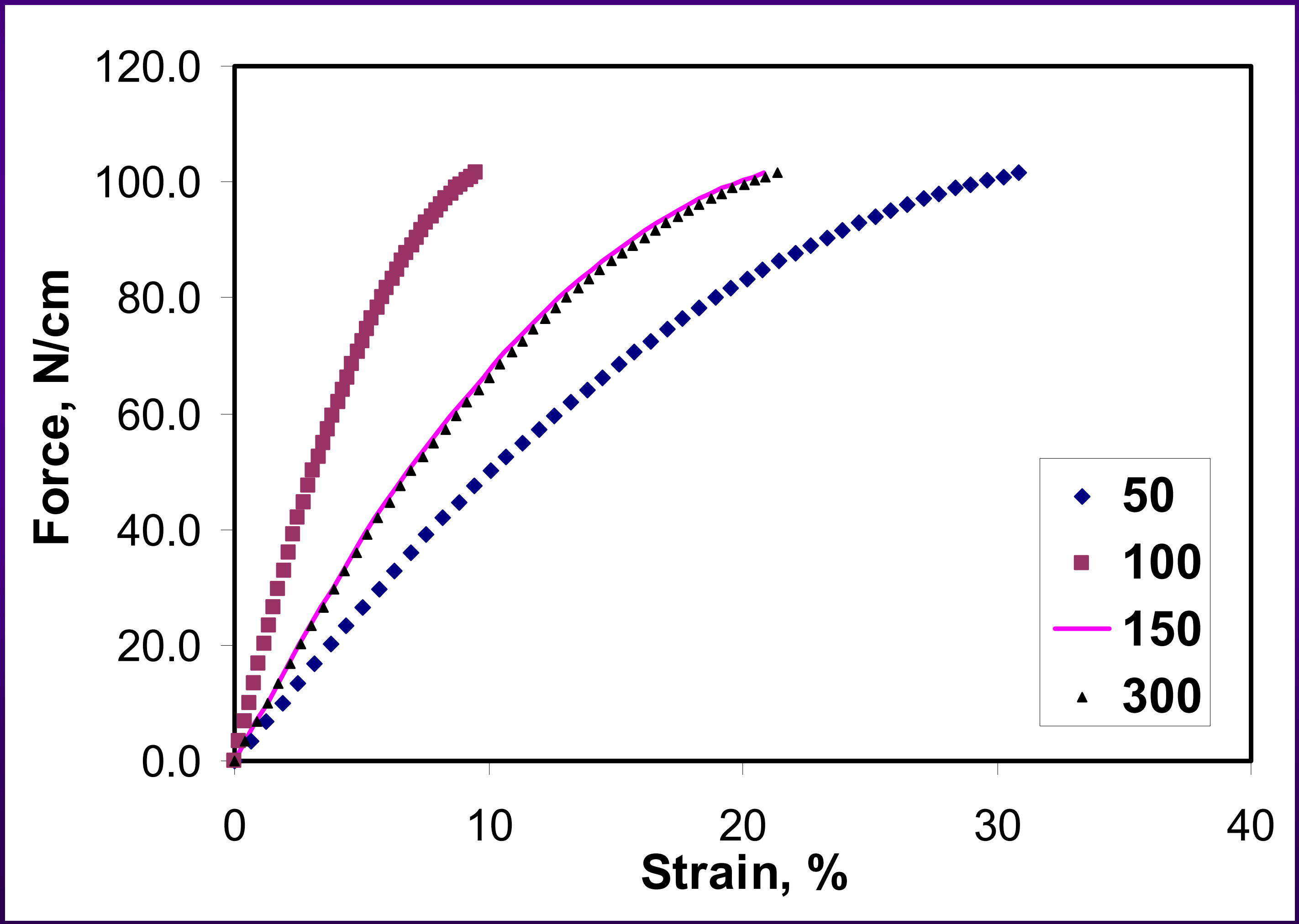
New method

- Summary so far..
  - Measure load-displacement from zero, short span tests
  - Zero span test- need stress-strain curve to convert displacement to strain.
  - Short span test- displacement is sum of displacements under the jaw (zero-span test) and free span between jaws.
- New method:
  - For same force, subtract zero-span displacement from short-span displacement to give displacement due to free span. Convert to strain.

Load-displacement curves 0-300 micron spans, Unbleached kraft (A), 6000 PFI revs refining



Stress-strain curves determined from subtraction, Unbleached kraft (A), 6000 PFI revs beating



Method limitations

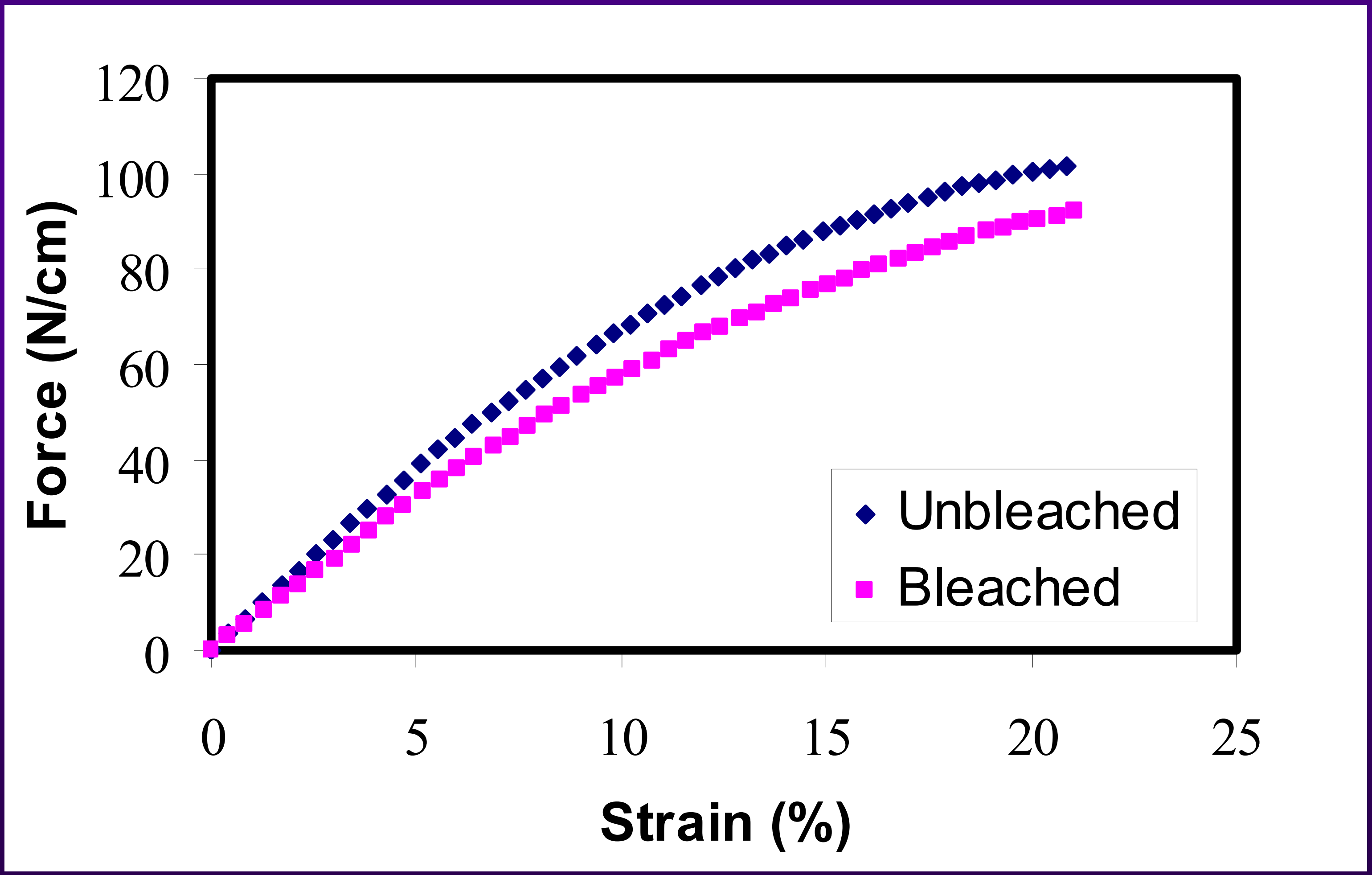
- Minimum span is 0.15 mm (150 microns)
  - Shorter spans- curves too close together, errors high
- Effect of span on stress-strain??
- Need to maximise term in brackets by
  - Long, straight fibres
  - Well beaten: low value of *c*- reduces effect of fibres not bridging between jaws

$$F_L = E_p \left[1 - c \frac{32}{9\pi} \frac{G}{\overline{l(0)}} \right] \frac{\Delta G}{G}$$

$$c = 1, \text{ unbonded}$$

$$\approx 0, \text{ long fibres, perfectly bonded}$$

Stress-strain curves determined from subtraction, Unbleached kraft and bleached kraft, 6000 PFI revs beating



Conclusions

- Load-displacement curves measured for several pulp types
- New method developed to use short and zero-span measurements to obtain stress-strain curves
- An unbleached kraft sample, heavily refined-breaking strain of 20%, considerable plastic deformation

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