Temap

Helping you solve the Fibre Puzzle

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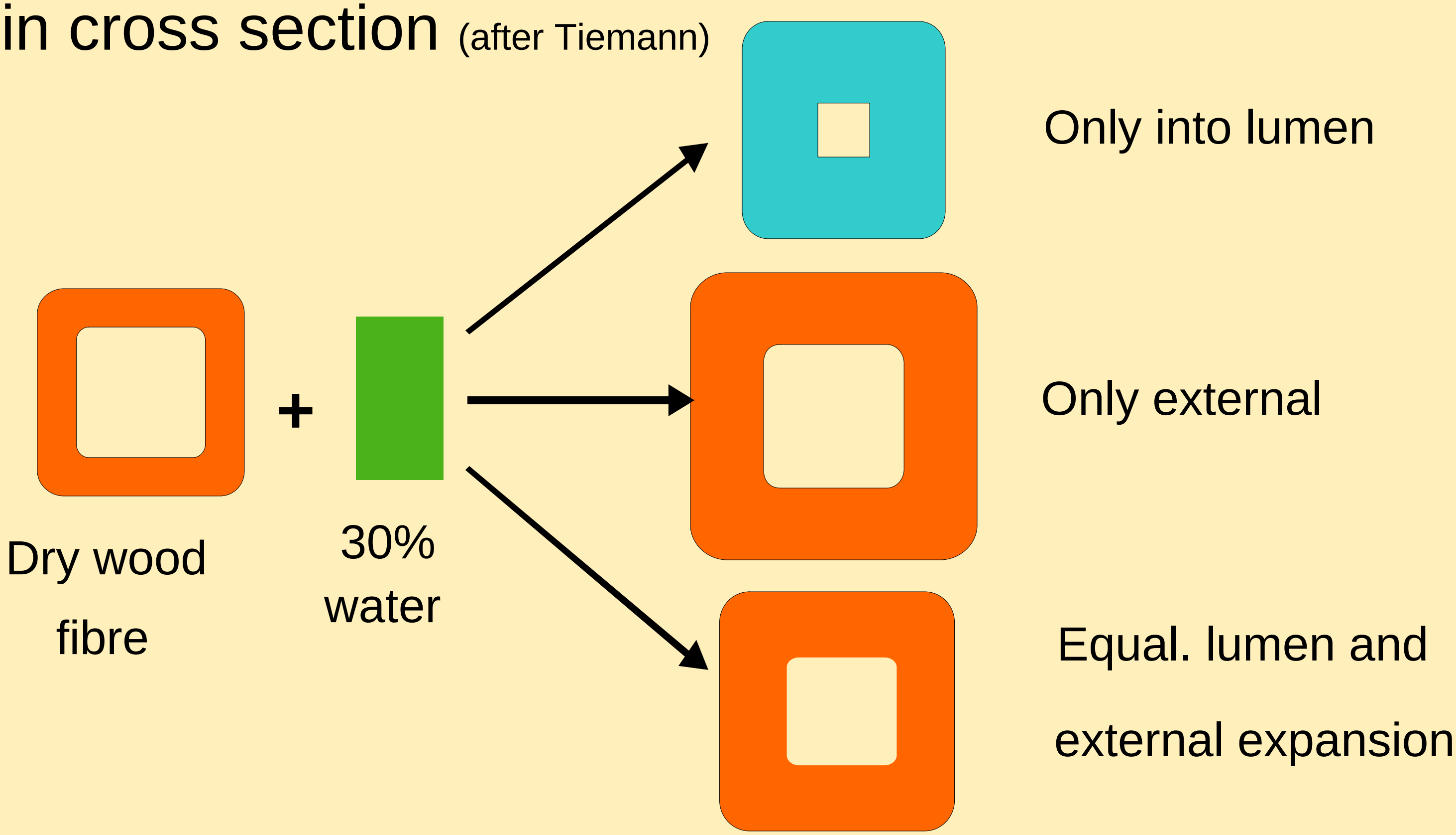
Paper Shrinkage, Expansion and Dimensional Stability

Volumetric Swelling of a Fibre (1)

- Schematic illustration of the volumetric swelling of a fibre in cross section (after Tiemann)



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Volumetric Swelling of a Fibre (2)

- Longitudinal swelling is negligible
- Generally cellulose fibres swell such that pore volume remains constant
- Swelling into lumen is limited due to the high fibril angle of the S3 layer

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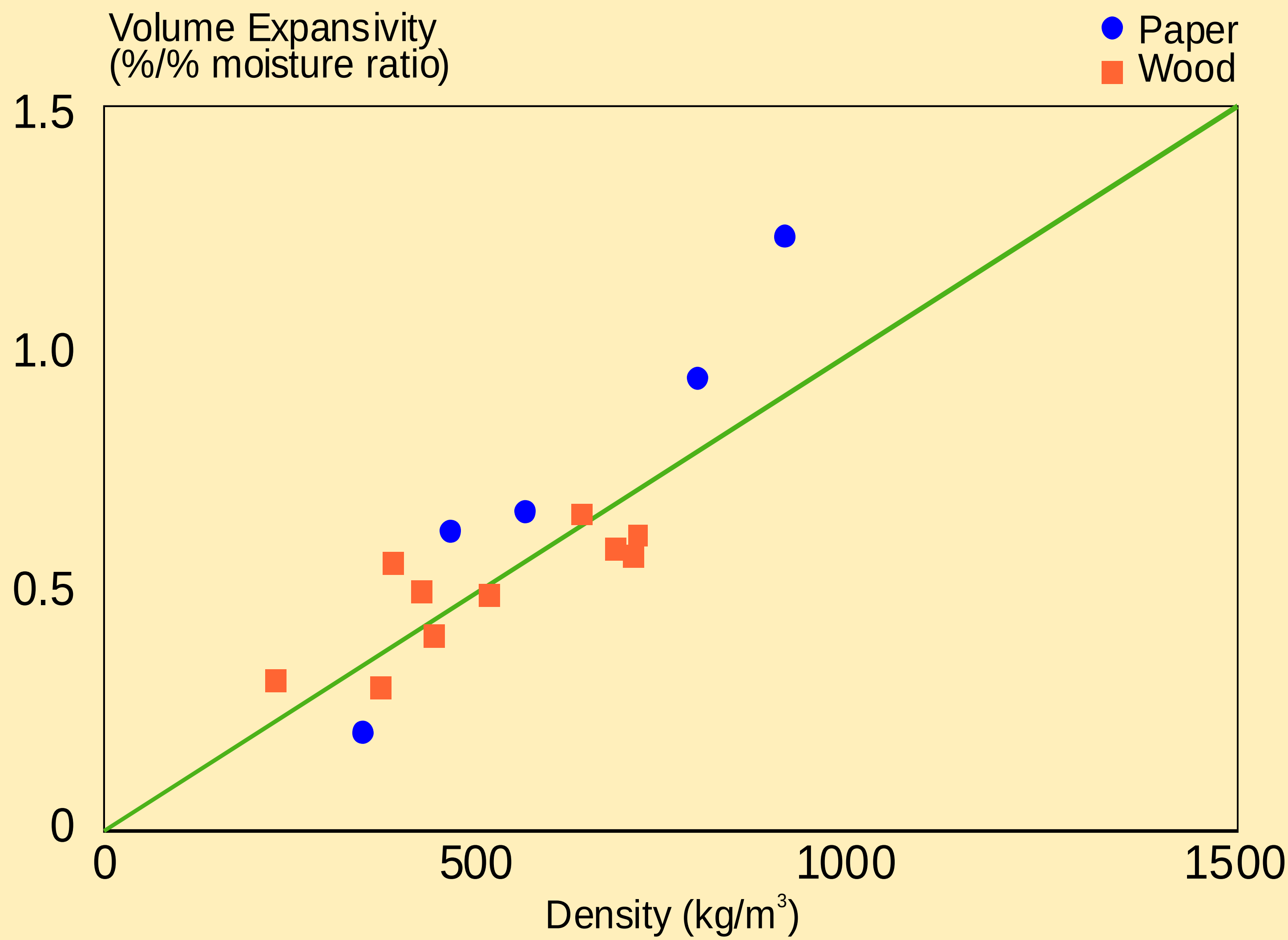
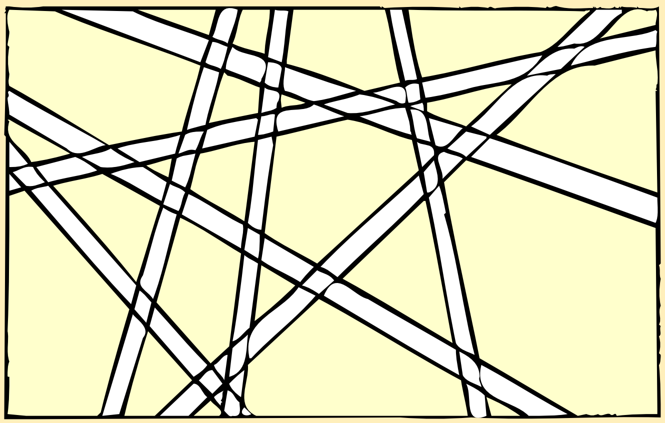
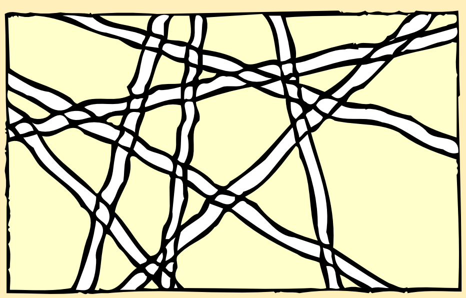
Volumetric Expansion and Density



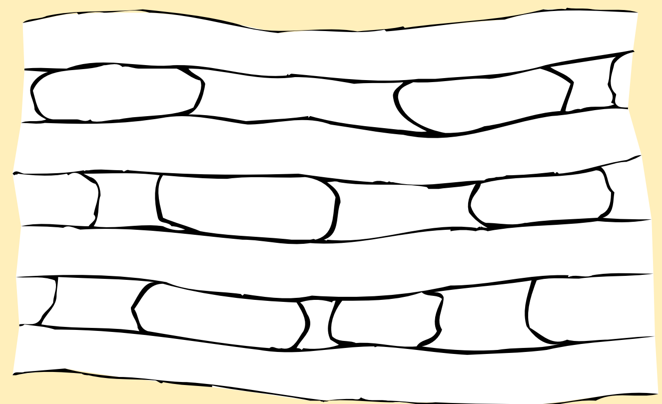
Schematic Representation of Sheet Shrinkage (1)



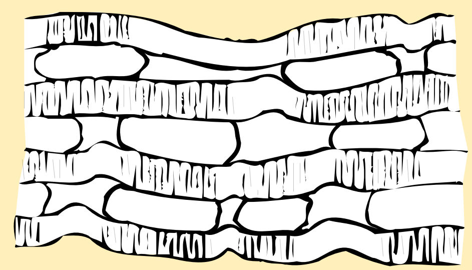
(a)



(b)



(a)



(b)

Source: Page & Tydman, 1962

Schematic Representation of Sheet Shrinkage (2)

- Shrinkage of bonded fibre crossings enforces a longitudinal shortening of fibre to retain structure
- Fibres became micro-compressed during sheet shrinkage
- At similar fibre diameters, thin walled fibres shrink more than thick walled fibre

Source: Page & Tydman, 1962

Drying Shrinkage

- A function of pulp properties and papermaking variables
  - fibre orientation, wet pressing, draws
- Associated with many papermaking problems:
  - dryer wrinkles
  - dryer cockle
  - grainy edge
  - fuser curl
  - stack lean
- The major papermaking variable affecting sheet shrinkage is fibre orientation

Drying Shrinkage and Hygroexpansion (1)

- Often used to characterise “dimensional stability”

	TMP	GWD	CTMP	CMP	LYS	Beaten LYS	Beaten BKP
(Restraint-dried sheets)							
Hygroexpansion coefficient (%/%M.C.)	0.057	0.068	0.063	0.081	0.048	0.063	0.053
Wet-expansion %	-	0.17	-	0.32	0.50	0.57	-
(Freely-dried sheets)							
Hygroexpansion coefficient (%/%M.C.)	0.074	0.086	0.087	0.125	0.075	0.123	0.092
Wet-expansion (%)	1.26	1.14	-	2.36	1.57	2.45	-
Drying shrinkage (%)	1.40	1.50	1.99	3.06	2.35	4.60	3.23

- They are not directly correlated with the hygroexpansion coefficient
  - DS/WE lowest for TMP and GWD but not for HC

Source: Nanri & Uesaka, September 1991

Drying Shrinkage & Hygroexpansion (2)

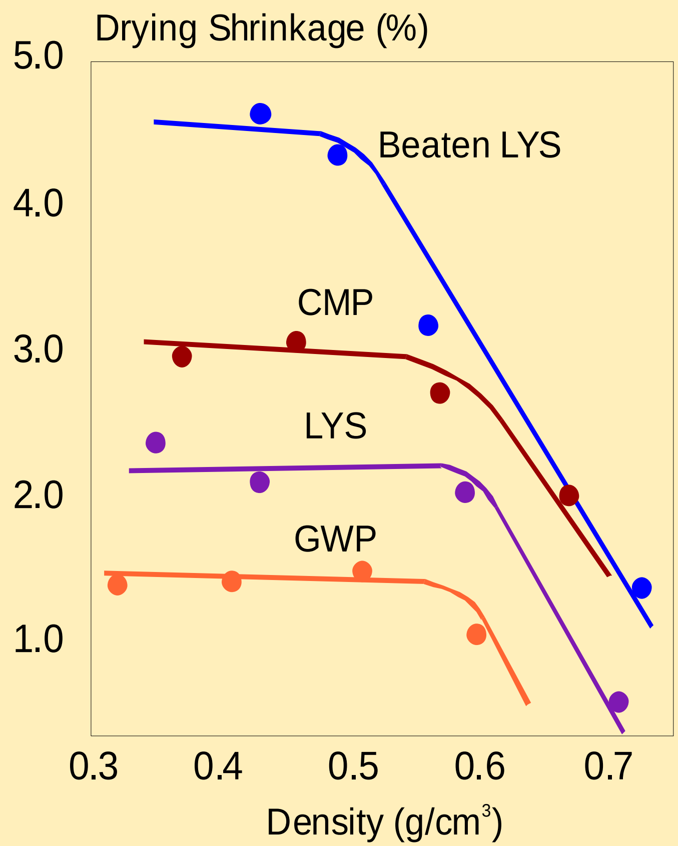
- Drying shrinkage seems to be directly related to degree of chemical modification (sulphonation)
- TMP and GWD produce the lowest sheet shrinkage, kraft pulp has the highest
- Hygroexpansivity increases (+20%) as fibre length decreases (2.6 → 0.7 mm)
- Hygroexpansivity increases as degree of bonding increases. Magnitude of increase is much lower when sheets are dried under restraint.

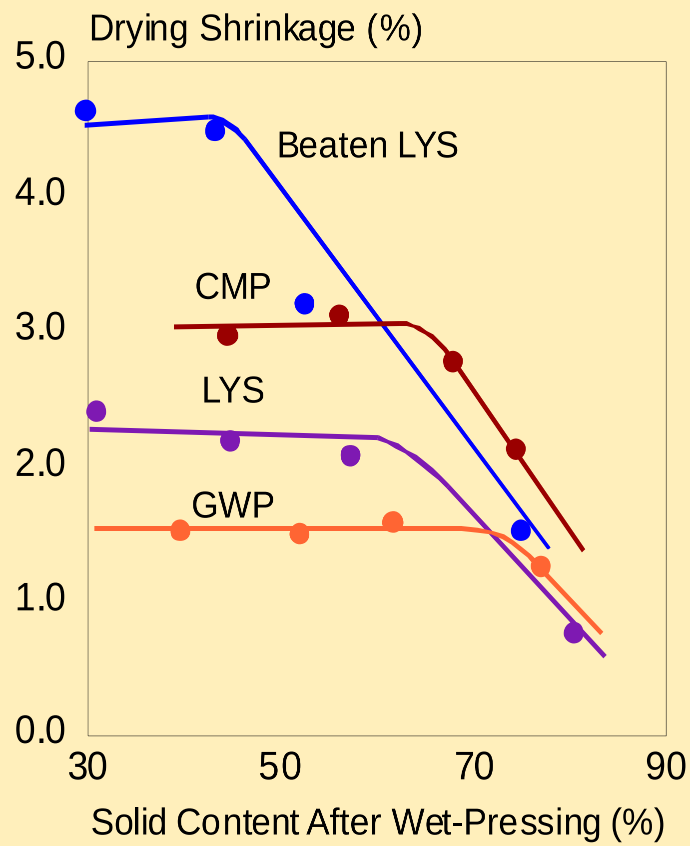
Source: Uesaka & Qi, December 1992

Drying Shrinkage & Hygroexpansion (3)

- Chemical fibres have highest degree of shrinkage
- Fines fraction of both chemical and mechanical pulps has greater hygroexpansion than either whole pulp
- Refining can alter these effects
  - high consistency ➔ curl ➔ shrinkage up/hygroexpansion up
  - low SEL ➔ less fines ➔ shrinkage down/hygroexpansion down
- Secondary fines (from refining) have a far greater effect on shrinkage and hygroexpansivity than primarily fines (from wood)
- Hemicellulose content affects water retention value. Higher WRV gives greater shrinkage and hygroexpansivity.

Shrinkage During Drying (1)





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Shrinkage During Drying (2)

- Drying shrinkage is constant until a critical density is reached
- Drying shrinkage can fall as sheet solids content increases
- Wet pressing increases fibre bonding through sheet compaction and also by removing water it reduces the degree of drying induced shrinkage

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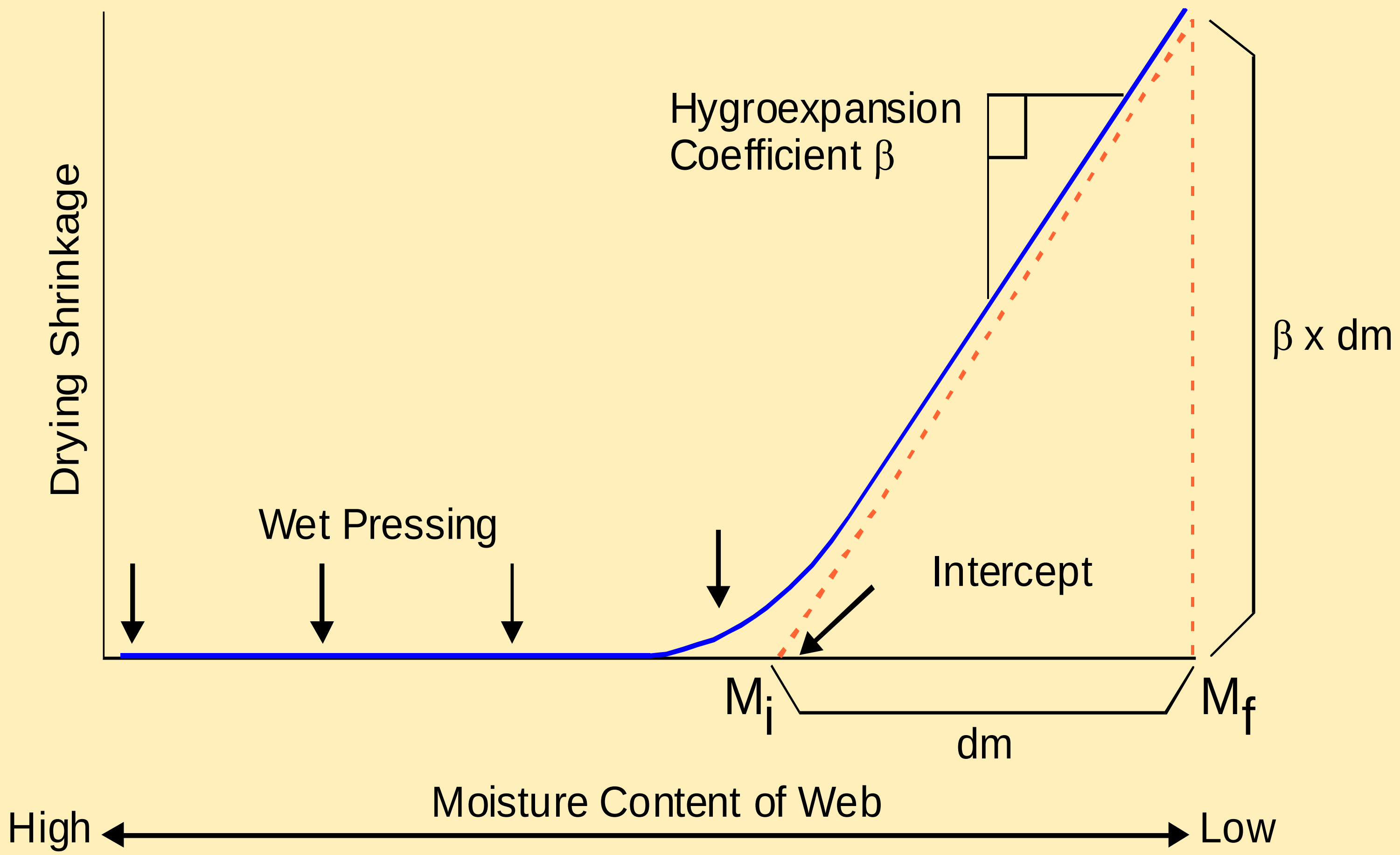
Shrinkage During Drying (1)

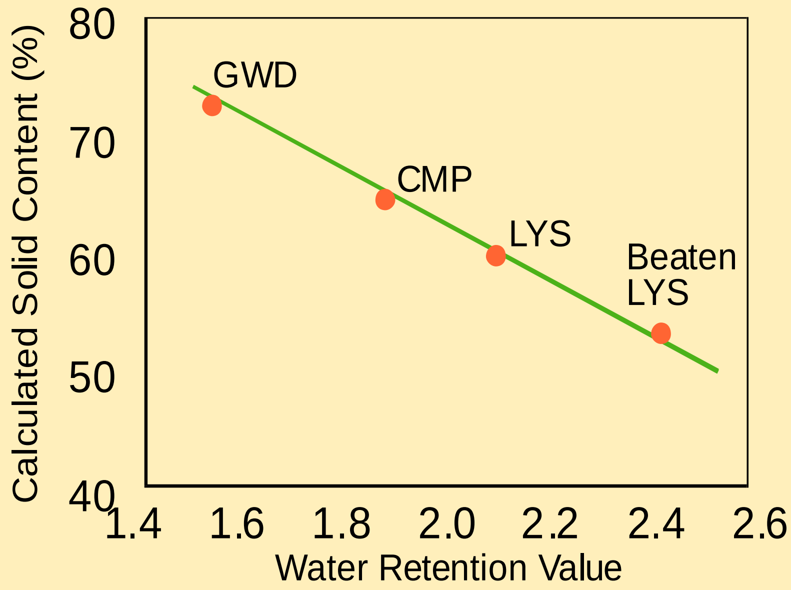


Shrinkage During Drying (2)

- During drying the web starts to shrink at a certain solids content
- Shrinkage can be described as the product of the slope of the drying shrinkage curve and the change in moisture

  - drying shrinkage = $ß \times {}_{d}m$

Shrinkage During Drying



- Solids content at intercept point (Mi) is proportional to water retention value (WRV) of pulp. This is easy to measure.
- WRV is directly proportional to hemicellulose content

Shrinkage During Drying

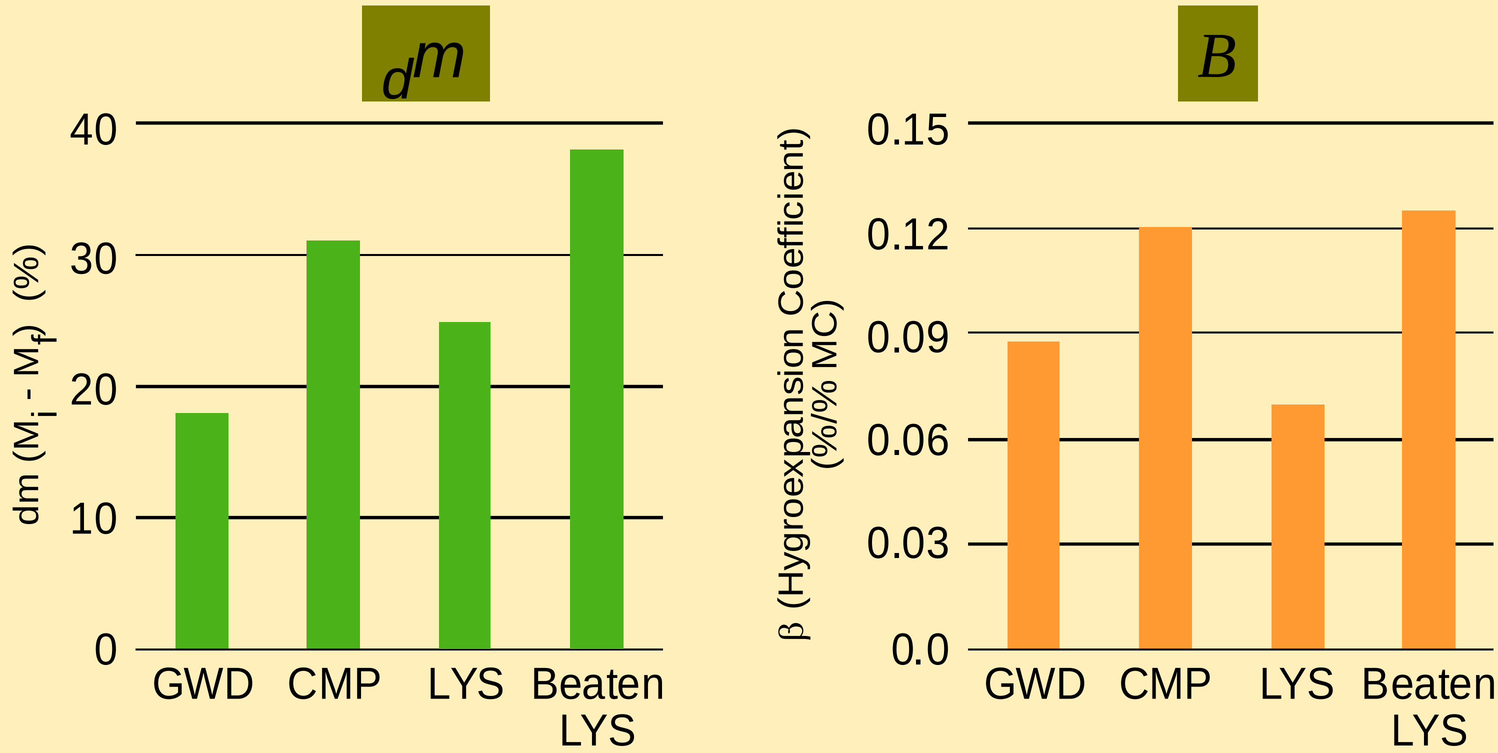
- We see that :

  drying shrinkage = hygroexpansivity x moisture change

  (ß) *($_d m$)*

- This means that either *ß* or $_d m$ affect the degree of drying shrinkage

Shrinkage During Drying



- The low shrinkage of GWD is due to low dm, not to a low hygroexpansion coefficient

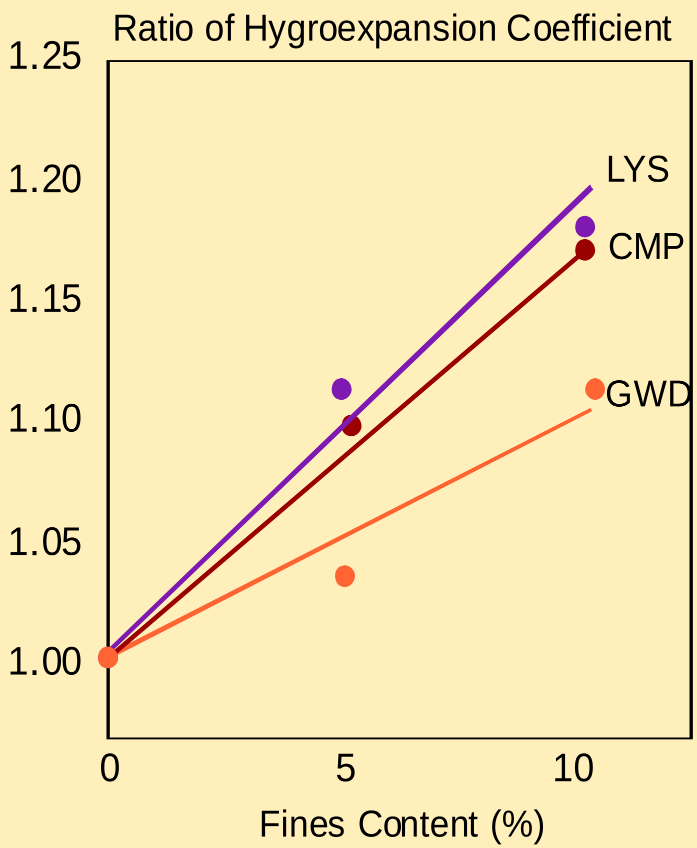
Effect of fibre length on Drying Shrinkage and Hygroexpansion

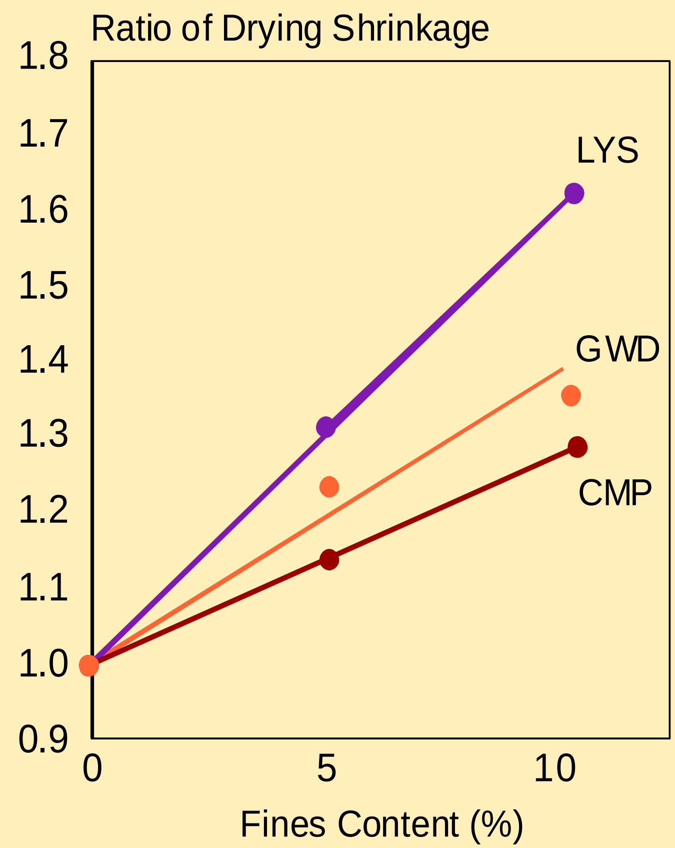
- We have seen earlier that hygroexpansivity increases as fibre length decreases
- Thus fibre shortening would be expected to increase the dimensional instability. In this context, fibre shortenining is independent of fines generation.
- Other things being equal, then hardwoods can be slightly more reactive than softwoods
- Refining should be minimised and optimised to reduce fines generation and fibre shortening

Effect of Fines on Drying Shrinkage and Hygroexpansion

- Fines content and type controls many properties of mechanical pulp
- Fines have a high “swelling ability”, and they contribute to fibre bonded area and bond stiffness
- Increasing fines content increases drying shrinkage and hygroexpansivity for kraft and mechanical pulps
- In mechanical printing papers the chemical pulp controls shrinkage but the mechanical pulp fines control hygroexpansion

Effect of Fines on Drying Shrinkage (1)



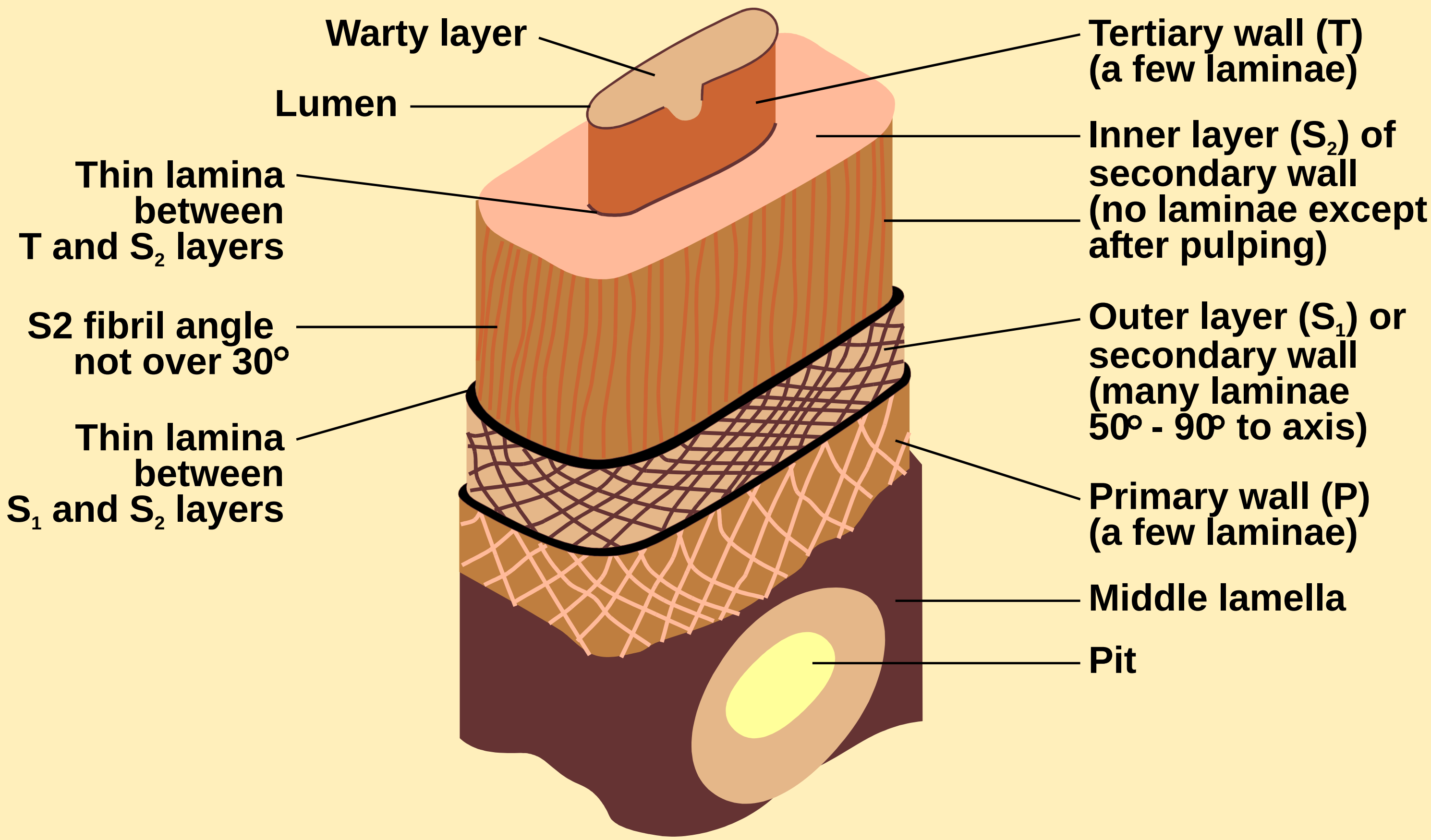


Effect of Fines on Drying Shrinkage (2)

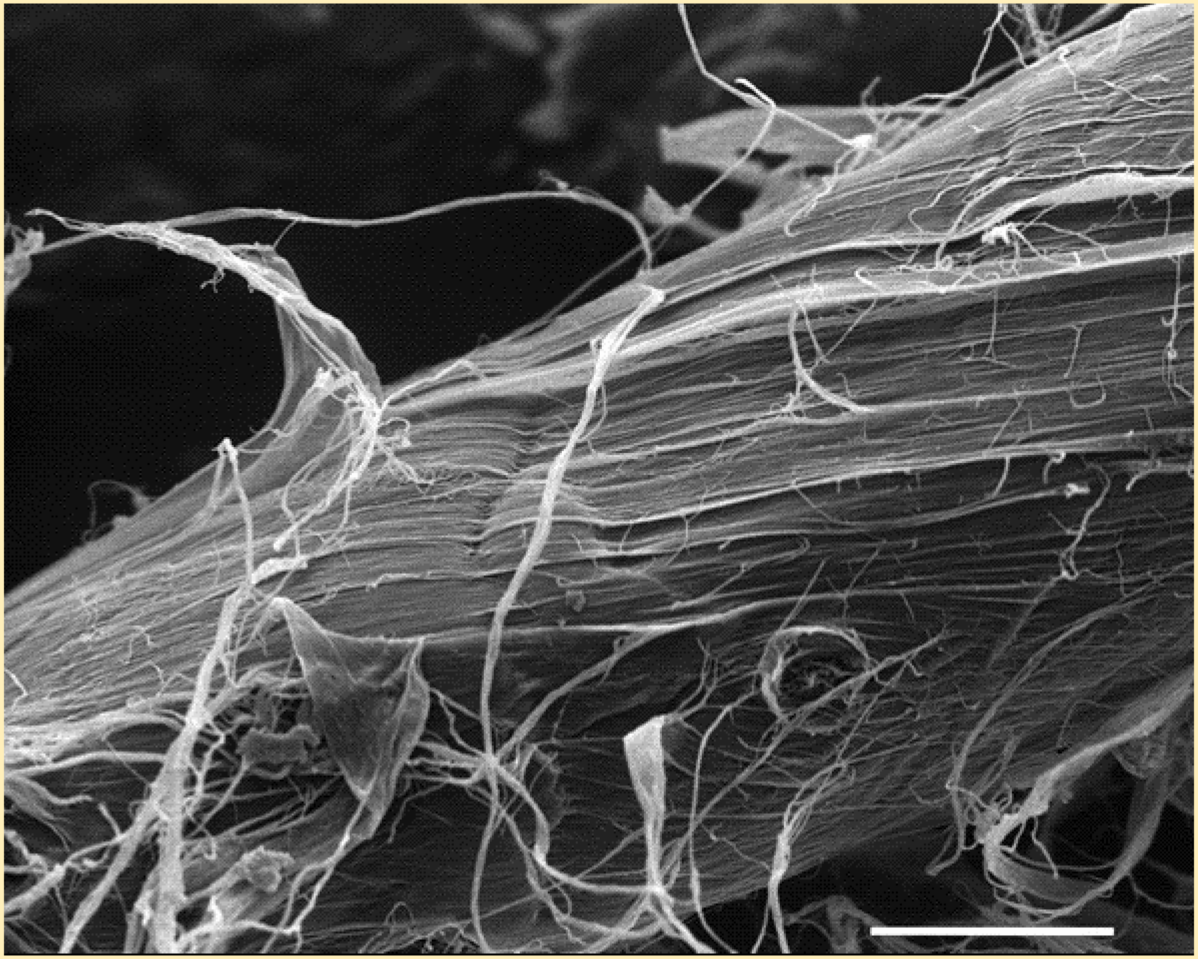
- Chemical pulp fines contain highly ionic groups and are mostly small fibrils. They can swell and thus increase fibre - fibre bonding more than less sulphonated fines.

- The effect of fines on hygroexpansion or drying shrinkage is large

Sketch of a Typical Tracheid

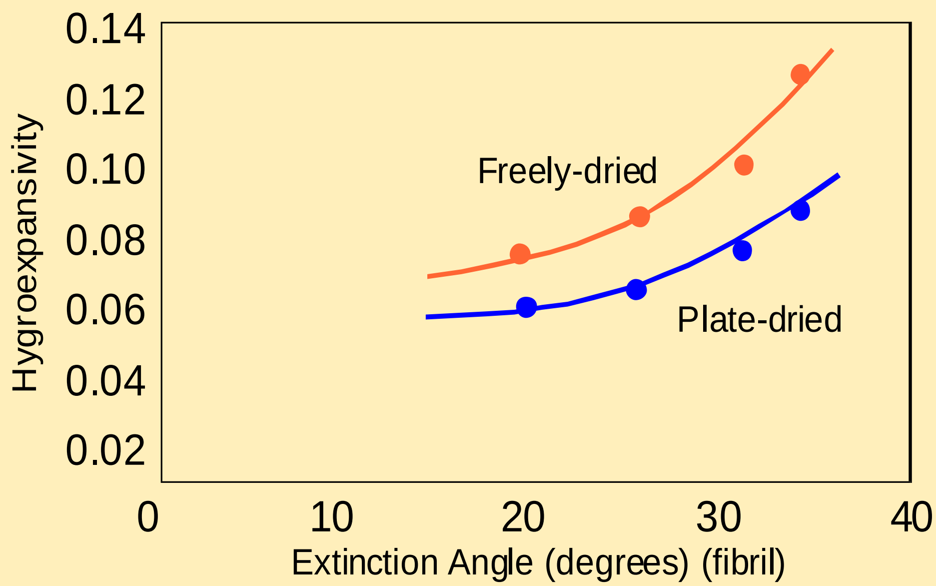


External Fibrillation
Fibril Angle



BRD 78 34

Effect of Fibril Angle on Hygroexpansivity



- Low fibril angles produce less hygroexpansion
- S2 fibril angle is higher in springwood than summerwood, therefore springwood/summerwood ratios can have an influence

Source: Uesaka & Moss, 1996

Effect of Wood Type on Hygroexpansion

	Extinction Angle (degrees)	Hygroexpansion Coefficient
Mature	14	0.044
Juvenile	18	0.053
Top wood	19	0.053

(Douglas-fir 3000 revs PFI)

- Juvenile wood fibres produce sheets with greater hygroexpansivity

Source: Uesaka & Moss, 1996

Internal Delamination – result of low intensity refining

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Summary

- Optimise fibre orientation – ultrasonic techniques better than strength ratios
- Affect of PM draws
- Maximise non-evaporative water removal
- Avoid fines generation
- Avoid pulps high in juvenile wood – plantations
- Avoid pulps high in hemicellulose – i.e. polysulphide
- Optimise / Minimise refining – use low SEL (get extreme strength from latexes etc?)
- Measure and control Water Retention Value (WRV)
- Some anecdotal evidence that N.American HW better than Eucalyptus or Scandianavian – juvenile wood perhaps?