EG60411 **Bio-Material Science**

Toshiharu Enomae

Professor, PhD, Paper Device and Eco-friendly materials

2G103, 10:10-11:25, Tuesday

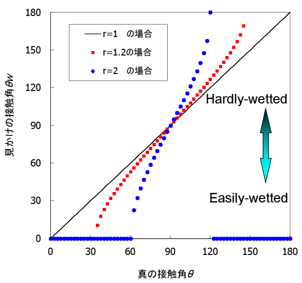
Biomaterial Science （Schedule）

#	Date	Content
1	4/15	History of papermaking
2	4/22	Pulps – Beating and fiber properties
3	5/9, Fri	Pulps – Additives and functions
4	5/13	Papermaking processes & interfiber bonding
5	5/20	Paper– Structural properties
6	5/27	Paper– Surface properties
7	6/3	Polysaccharide chemistry by Assoc Prof Akiko Nakagawa
8	6/10	Paper–Wetting and absorption properties
9	6/17	Paper– Mechanical and optical properties
10	6/24	Recent trend of paper science and technology

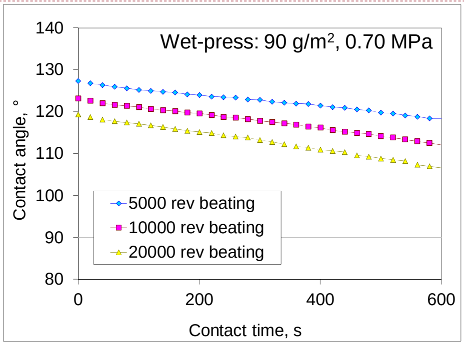
Surface chemistry - Contact angle

- Wenzel's equation
  - On a rough surface, when $\theta_w < \theta$ at $\theta <$ 90°, easily-wetted surfaces become more easily-wetted. But, when $\theta_w > \theta$ at $\theta >$ 90°, hardly-wetted surfaces become more hardly-wetted.

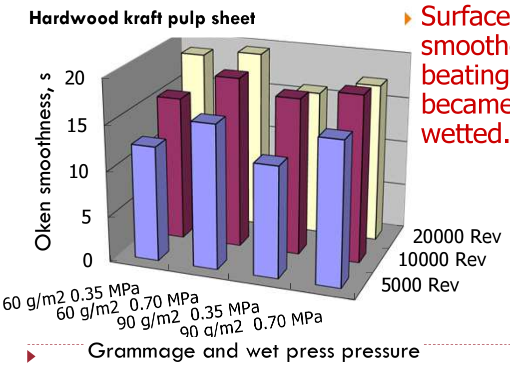
$$\cos\theta_w = r\cos\theta$$



Contact angle of paper - Beating effect



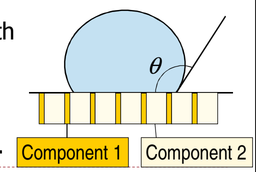
Beating and smoothness



- Surfaces smoothed by beating became easily-wetted.

Surface chemistry - Contact angle

- On composite surfaces
  - The effective contact angle θ_C is dependent on the areal ratio of each component.
- Cassie's law
  - is stated as $\cos\theta_C = Q_1\cos\theta_1 + Q_2\cos\theta_2$, where θ_1 is the contact angle for component 1 with areal fraction Q_1 and θ_2 is the contact angle for component 2 with areal fraction Q_2 ($Q_1 + Q_2 = 1$).



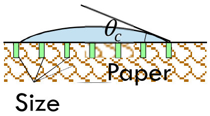
Surface chemistry - Contact angle

Q. What is the contact angle θ_c of sized paper?

- Sizing agent need not cover the whole surface of fibers for repelling water. If a sizing agent covers 5% of the whole surface, what is the contact angle θ?
- Assume that θ is 0° for unsized fibers and 120° for the covering size.
- $\cos\theta_c$ = (G) × cos 0° + (H) × cos 120°

  $\cos\theta_c$ = (I) = 0.925

  θ_c = (J)



Surface chemistry - Contact angle

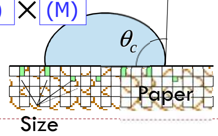
Q2. What is the contact angle θ_c of sized paper?

- Half the volume of paper is air. If 50% of paper surface is air, what is the θ_c?
- Assume that θ_c of a true surface of sized paper is 22.3° and θ of air is 180°.
- $\cos\theta_c$ = (K) × cos 22.3° + (K) × cos 180°

  $\cos\theta_c$ = (K) × (L) + (K) × (M)

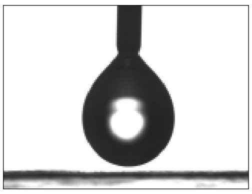
  = (N)

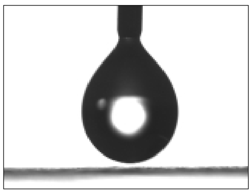
  θ_c = (O)



Surface chemistry - Contact angle

- **Comparison in Water absorption**





Parchment | **Wood-containing paper**

"wood-containing" means "made from mechanical pulp"

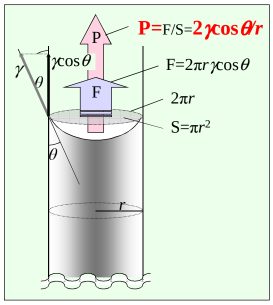
Liquid absorption theory - Capillary model

- Force developing around a meniscus of a liquid in a capillary (pipe)
- Steady flow in a pipe

$$Q = \frac{\pi P r^4}{8\eta l}$$

l: **Capillary length**
r: **Capillary radius**
η: **Liquid viscosity**
Q: **Volumetric flow rate**

(Hagen-Poiseulle equation)



Liquid absorption theory - Capillary model

Q. Substitute the relation represented in the figure into the H-P equation and develop the Lucas-Washburn equation.

- H-P equation

$$Q = \frac{\pi P r^4}{8\eta l}$$

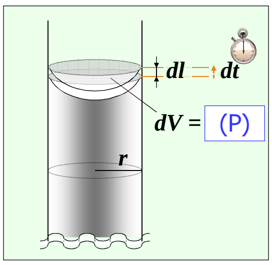
$$P = \frac{2\gamma\cos\theta}{r}$$

$$Q = \frac{dV}{dt} = \text{(Q)}$$

Substitute

- Lucas-Washburn equation

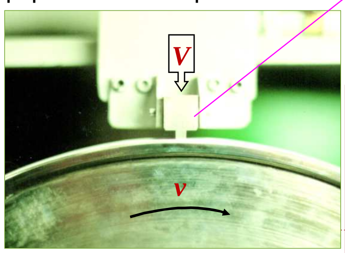
$$l = \sqrt{\frac{r\gamma\cos\theta\cdot t}{2\eta}}$$

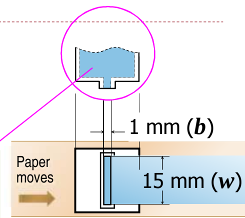


Water absorption rate - How to measure

- Bristow's apparatus

A liquid supply head filled with a liquid of volume V scans paper at various speeds v.

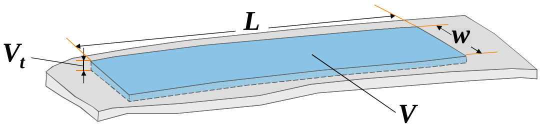




- **Contact time** $t = b / v$
  - Scan speed v
  - Slid width b
- **Transfer Vol** $V_t = V/(wL)$
  - Liquid volume V
  - Slit width w
  - Trace length L

Water absorption rate – How to measure

- Calculate transferred volume per unit area V_t



- **Contact time $t = b/v$**
  - Scan speed v
  - Slid width b
- **Transfer Vol $V_t = V/(wL)$**
  - Liquid volume V
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  - Trace length L

Water absorption rate – Water and oil

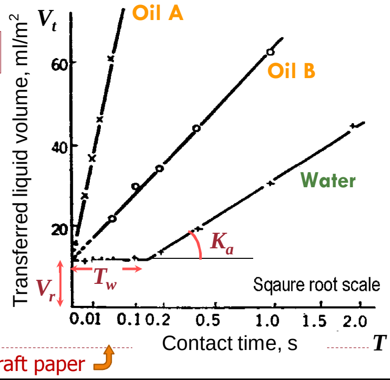
- For water,

$$V_t = V_r + K_a\sqrt{T - T_w}$$

V_r Roughness index
T Contact time
T_w Wetting delay
K_a Absorption coeff.

- For oil, $T_w = 0$.
  Then,

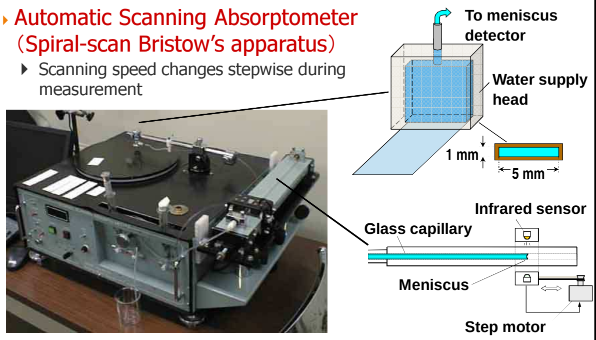
$V_t =$ (Q)



- Bristow's plot of kraft paper

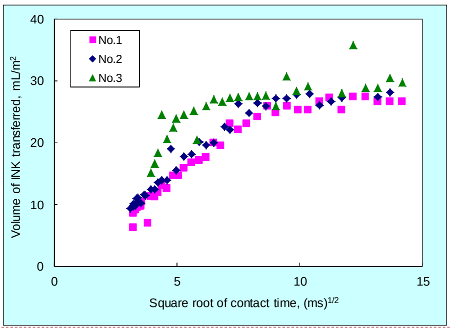
Water absorption rate - How to measure

- Automatic Scanning Absorptometer (Spiral-scan Bristow's apparatus)
  - Scanning speed changes stepwise during measurement

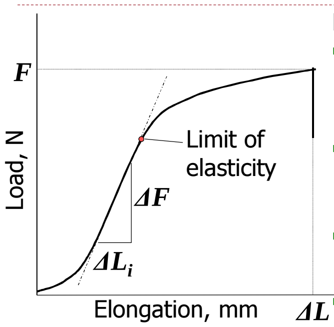


ASA

Water absorption rate of ink jet paper -ASA



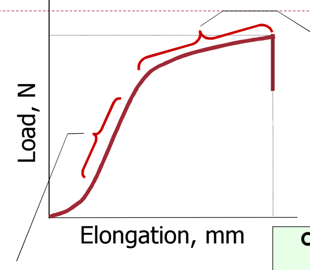
Mechanical properties –Tensile strength



Load-elongation curve

- Method
  - 15 mm in width
  - 100 mm in span
  - 10 mm/min elong speed
- Tensile index I
  - $I = \frac{F}{wg}$ (w: width g: grammage)
- Strain at break ε_T
  - $\varepsilon_T = \frac{\Delta L}{L}$
- Modulus of elasticity E^*
  - $E^* = \frac{\Delta F}{\Delta LiwT}$ (T: thickness)

Mechanical properties –Tensile strength

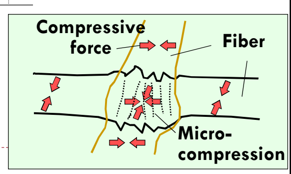


Plastic region

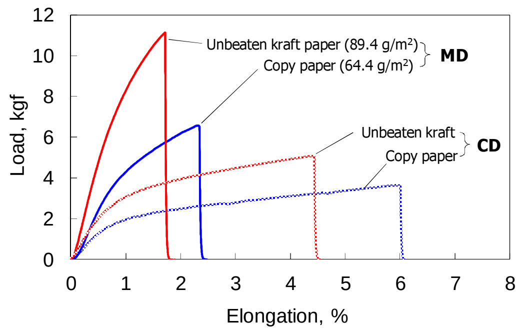
- Extension of curl
- Extension of micro-compression
- Breakage of inter-fiber bonds
- Breakage of fibers

Elastic region

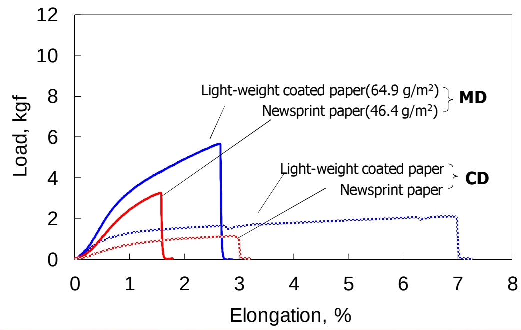
- Elastic elongation of fibers
- Elastic elongation of fiber network



Anisotropy–Tensile strength



Anisotropy–Tensile strength



Q. Why does light-weight coated paper elongate greatly?

Mechanical properties – Stiffness

- (Bending) stiffness S represents the degree to which paper resists bending

$S=Mr$

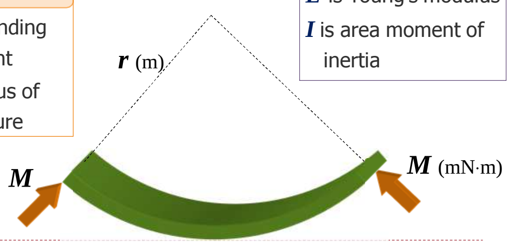
M is bending moment

r is radius of curvature

$S=EI$

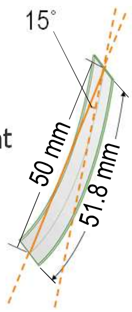
E is Young's modulus

I is area moment of inertia



Mechanical properties – Stiffness

- Taber Stiffness
  - Bending moment when a test piece 38mm wide is bent to 15° and load length 50 mm
  - The unit is mN·m



Mechanical properties – Folding endurance

- Folding endurance
  - logarithm number of double folds at 120° on both sides that are required to make a test piece break
  - Longer fibers tend to show higher values.