EG60411 **Biomaterial Science**

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

Biomaterial Science (2015 Schedule)

#	Date	Content
1	10/6	History of papermaking
2	10/13	Pulps – Beating and fiber properties
3	10/20	Pulps – Additives and functions
4	10/27	Papermaking processes & interfiber bonding
5	11/10	Paper– Structural properties
6	11/17	Paper– Surface properties
7	11/24	Paper–Wetting and absorption properties
8	12/1	Paper– Mechanical and optical properties
9	12/8	Polysaccharide chemistry by Assoc Prof Akiko Nakagawa
10	12/15	Recent research of paper science and technology
11	12/22	Examination

Lecture information and contact

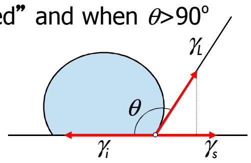
- Homepage of "Biomaterial Science (T. Enomae)"
- http://www.enomae.com/
  → Handouts in lecture(講義資料)
- E-mail address
  → t@enomae.com
  for any questions and visit to laboratory
  (Bio-Agr. Bldg. 生農C209 or 総合A618)

Interaction– between paper and water (liquid)

- Wetting
- Contact angle
- Surface energy
- Sizing degree
- Liquid penetration
- Swelling

Surface chemistry – Contact angle

- Contact angle (θ)
  - The angle made by the solid and liquid surfaces when a liquid droplet is placed on a solid surface.
  - When 0°< θ < 90°, "wetted" and when θ>90° "unwetted".
- Young equation
  - When the contact angle is constant, horizontal components of forces are balanced.

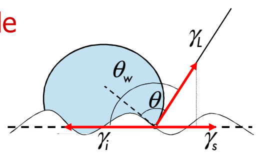


$$\gamma_i - \gamma_s + \gamma_L \cos\theta = 0$$

Surface chemistry – Contact angle

- Contact angle on a rough solid surface
  - Supposed that the area including microscopic structure is ***r*** times larger than the apparent one,
  - Wenzel's contact angle

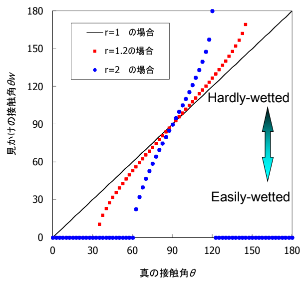
$$\cos\theta_w = r\cos\theta$$



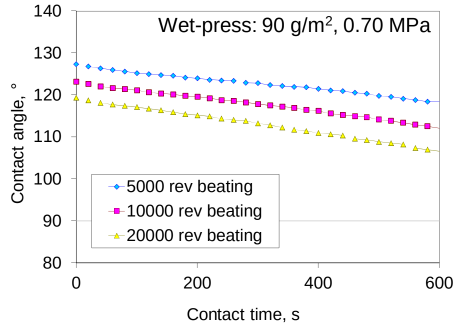
Surface chemistry － Contact angle

- 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.

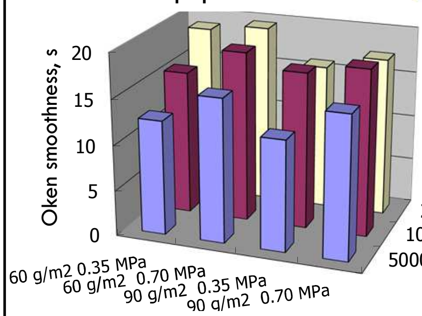
$$\cos\theta_w = r\cos\theta$$



Contact angle of paper － Beating effect



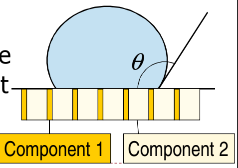
Beating and smoothness



- Surfaces smoothed by beating became easily-wetted.

Surface chemistry － Contact angle

- On composite surfaces
  - The effective contact angle θ_C is dependent on the area 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 area fraction Q_1 and θ_2 is the contact angle for component 2 with areal fraction Q_2 ($Q_1 + Q_2 = 1$).



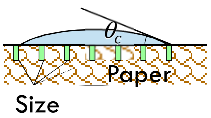
Surface chemistry － Contact angle

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

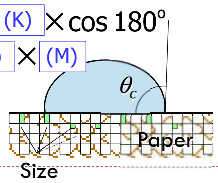
Q2. What is the contact angle θ_c of sized paper?

- 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)

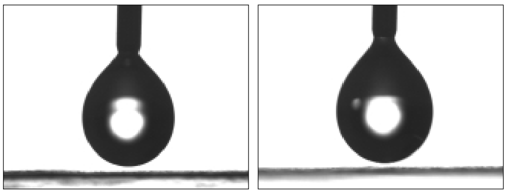
= (N)

θ_c = (O)



Surface chemistry – Contact angle

- **Comparison in Water absorption**



Parchment **Wood-containing paper**

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

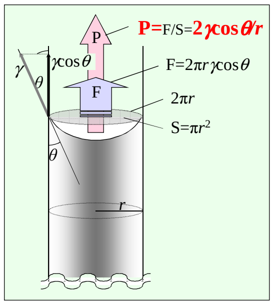
Liquid absorption theory - Capillary model

- 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

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

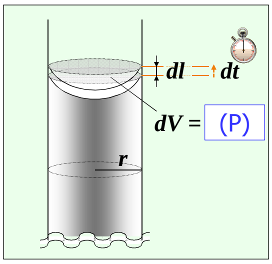
$$P = \frac{2\gamma\cos\theta}{r}$$

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

Substitute

- Lucas-Washburn equation

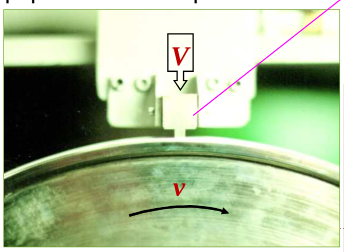
$$l = \sqrt{\frac{r\gamma\cos\theta \cdot t}{2\eta}}$$

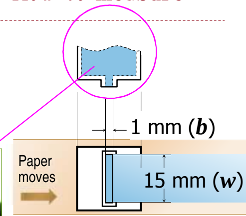


Water absorption rate – How to measure

- Bristow's apparatus

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



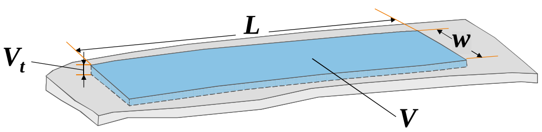


▸ **Contact time** $t = b / v$
Scan speed v
Slid width b

▸ **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
Slit width w
Trace length L

Water absorption rate – Water and oil

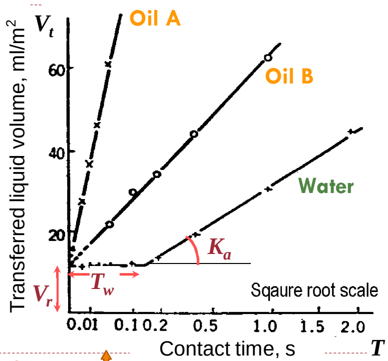
- For water,

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

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

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

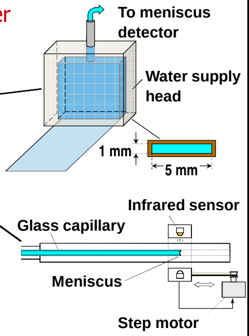
$$V_t = \text{(Q)}$$



▸ Bristow's plot of kraft paper

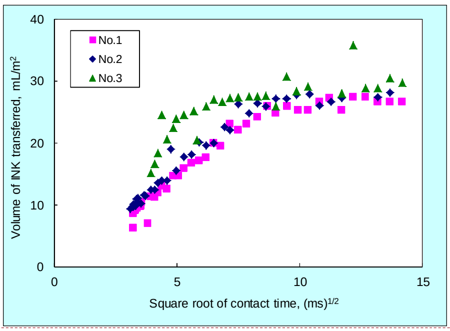
Water absorption rate – How to measure

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

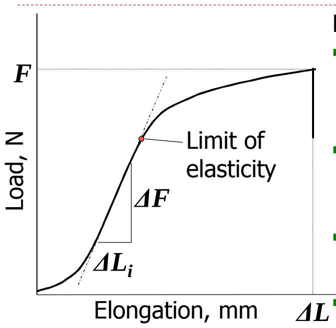


ASA

Water absorption rate of ink jet paper – ASA



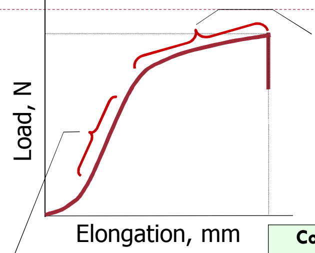
Mechanical properties – Tensile strength



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^*
  - $E^* = \frac{\Delta F}{\Delta L_i w T}$ (T: thickness)

Mechanical properties – Tensile strength

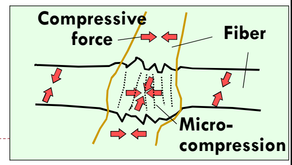


Plastic region

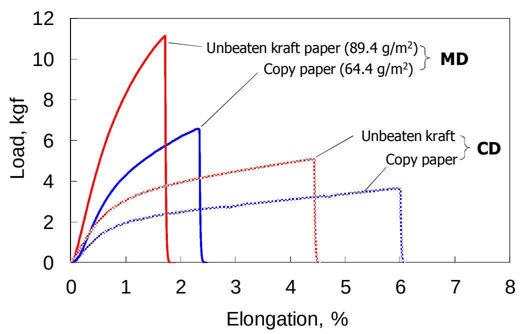
- Extension of curl
- Extension of micro-compression
- Breakage of inter-fiber bonds
- Breakage of fibers

Elastic region

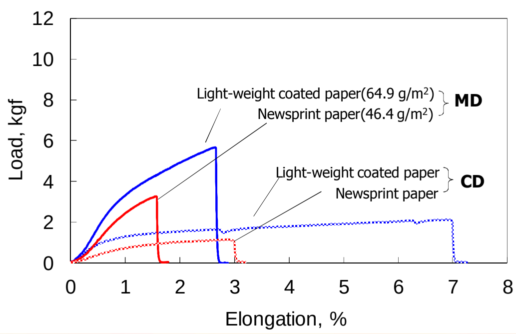
- Elastic elongation of fibers
- Elastic elongation of fiber network



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

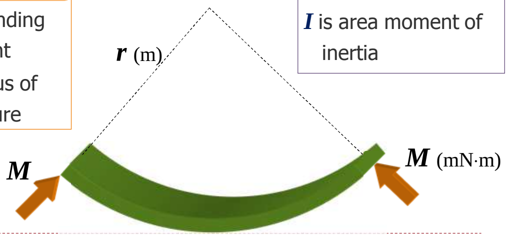
M is bending moment

r is radius of curvature

S=EI

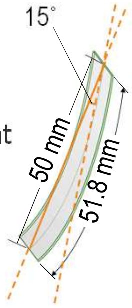
E is Young's modulus

I is area moment of inertia



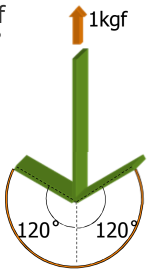
Mechanical properties – Stiffness

- 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.



Prospective future with Paper devices and Eco-friendly materials

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Research topics
Laboratory of Paper Devices and Eco-friendly Materials

- **Paper device** (Paper in future)
  - Paper electronics
    - Paper–based medical check-up sensor
    - Energy supply device
  - Paper-based bioassay system
- **Paper cultural heritage** (Paper in past)
  - Conservation Science
- **Fundamental papermaking technology** (Paper at present)
  - Paper coating, paper physics and chemistry, etc.

Development of Paper-based medical check-up sensor and technology of liquid transport in a micro-channel


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