Various Properties of Paper and their Testing

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FACTORS AFFECTING PROPERTIES OF PAPER:

- Types of raw materials
- Degree of delignification
- Types of pulping process
- Degree of refining or beating
- Filler loading
- Press load
- Calendaring
- Moisture content

A: Thick walled fibers B: Thin walled fibers

THE INFLUENCE OF THE ENVIRONMENT ON PAPER PROPERTIES:

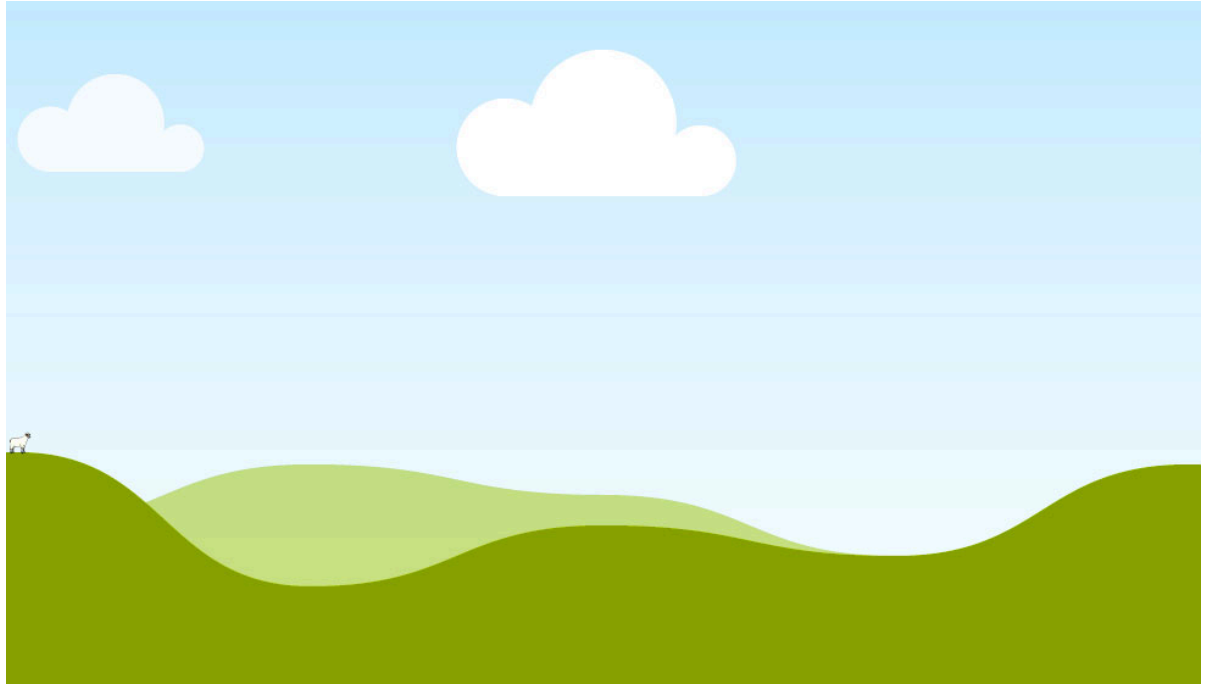
Conditioning a paper at a relative humidity of 65±2% and temperature 27 ^{o}C for 48 hours.

The effect of moisture on paper properties can be divided in to the following categories:

- **The effect on mechanical properties**
- **The effect on dimensional properties**
- **Other effects such as electrical properties, absorptive properties and ageing characteristics.**

Effect of moisture content on basis weight

A rule of thumb is that in the range of 20% to 60% change in relative humidity results in 1% change moisture content.



A precise basis weight correction over a range of 20% to 80% relative humidity.

Mechanical Properties:

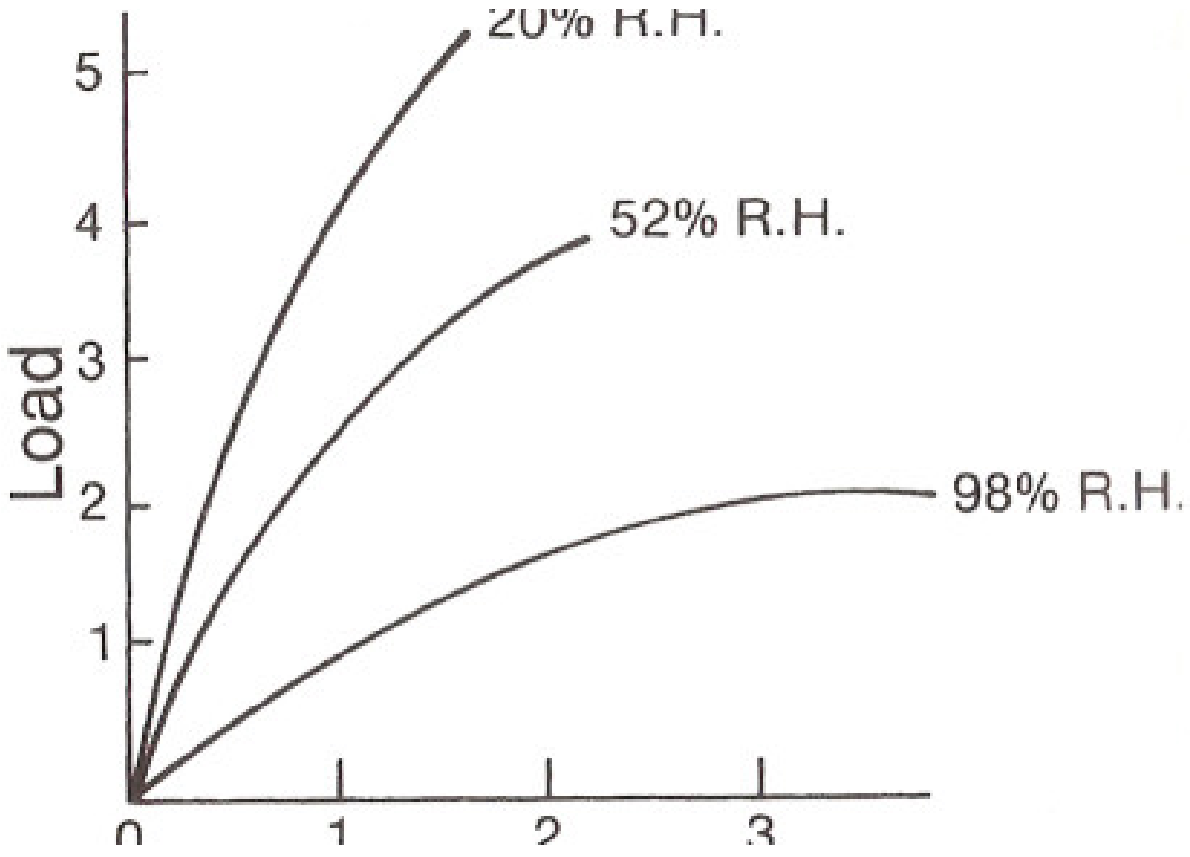


Figure 1:

Load elongation curve of paper at different relative humidity

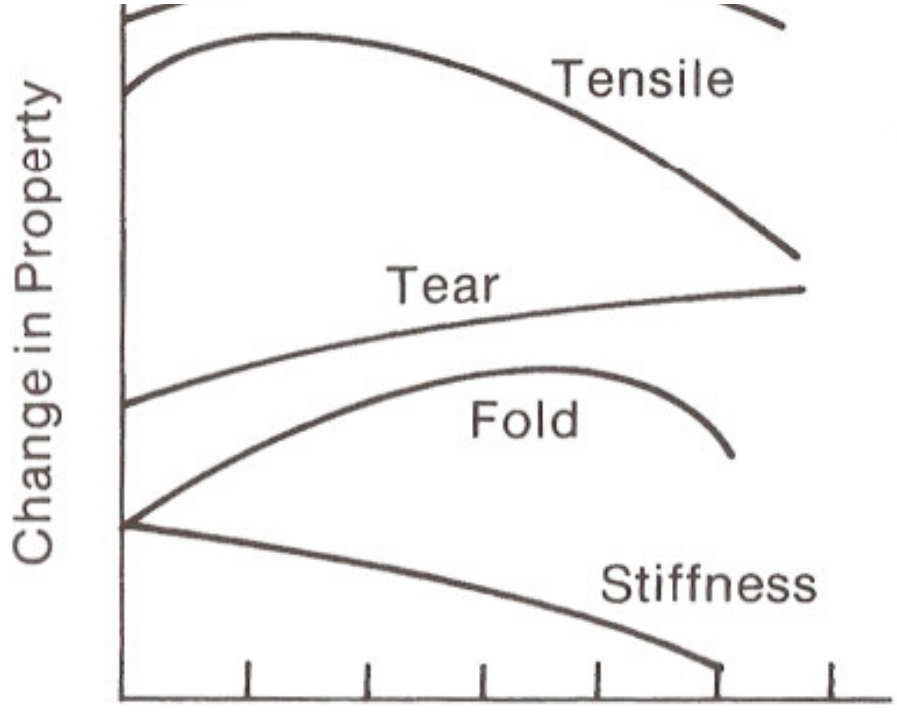


Figure 2:

Effect of relative humidity on mechanical strength properties

DIMENSIONAL INSTABILITY: Dimensions changes are due to:

The swelling or shrinkage of individual fibers when they absorb or desorb water

The relative fiber movements that occur due to fiber swelling and fiber to fiber bond weakening.

The distribution and magnitudes of stresses and strains built in to the sheet when it is manufactured.

MECHANICAL STRENGTH PROPERTIES OF PAPER

TEARING STRENGTH:

The work done in tearing is measured by the loss in potential energy of the pendulum.

It is crucial for applications like packaging, maps, and books where durability during handling and use is essential.

Tear strength depends upon:

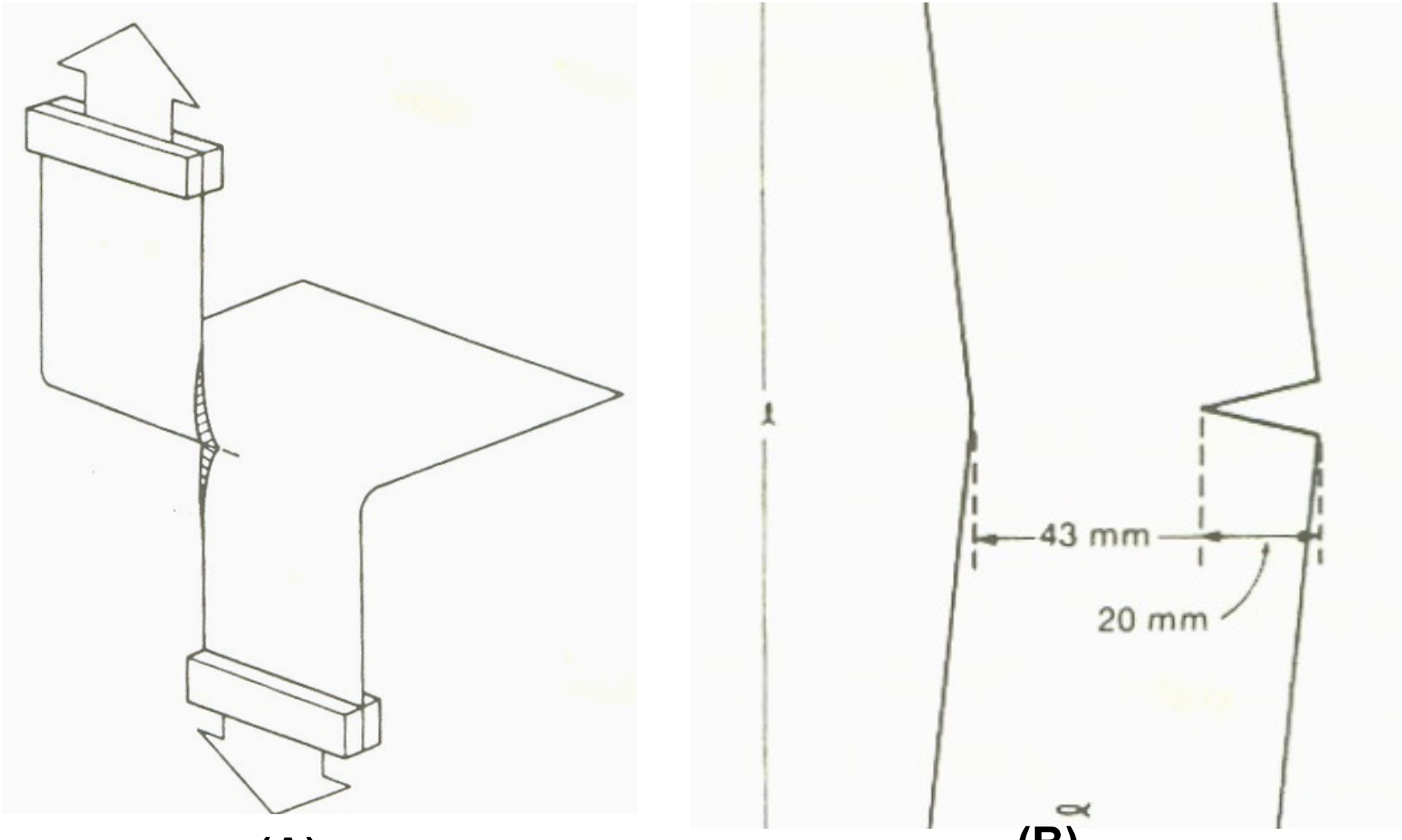
Fiber length

Fiber flexibility

First increases with increasing refining and then declines

The necessary work that has to be done to pull the fibers loose depends on the length of the fibers as well as the bond strength.

Tear strength is of two types:



(A) (B)

Figure 6

(A) Out plane tear **(B) In plane tear**

r a 16-ply test specimen, the given tearing distance is

K = 16X 4.3 (tearing distance per ply) X2 = 137.6 cm

The factor 2 being included since in tearing a given length the force is applied twice the distance.

Likewise, for a 16 ply test specimen, the tearing energy per ply for a scale reading of 100 would then be 100gf X 137.6 = 13760 gf. Cm

We know that one kgf.m = 9.80665 joules

If we have taken 8 sheets then,

X x 8 x 4.3 x 2 = 137.6

X = 137.6/8 x 4.3 x 2

X =2

Therefore, $\frac{13760 \text{ gf.cm X } 9.80665 \text{ X } 1000}{1000 \text{ X } 100} = 13760 \text{ X } 0.0980665 = 1349.4 \text{ Joules}$

One kgf = 9.80665 Newton

One gf = $\frac{9.80665}{1000}$ x 1000 = 9.80665 mN

For 1600 gf tensile tester with 0-100 scale

Average tearing force, mN = $\frac{16 \text{ x } 9.81 \text{ x Average scale reading}}{\text{Number of plies}}$

Average tearing force, gf = $\frac{16 \text{ x Average scale reading}}{\text{Number of plies}}$

Tear factor

$\frac{\text{Tearing strength}}{\text{Basis weight}} \text{ x } 100$

Tear index, mNm^2/g = Tearing force in mN x $\frac{m^2}{g}$

$$\frac{gf \text{ x } m^2 \text{ x } 1000 \text{ x} 9.80665}{g \text{ x} 1000 \text{ x } 100}$$

Tear factor x 0.0980665 = mNm^2/g

Using the formula:

Tearing force (mN) = (16 × 9.81 × Average scale

Examples:

- **Scale reading: 100, Plies: 2**
  → Tearing force = (16 × 9.81 × 100) / 2 = **784**
- **Scale reading: 85, Plies: 4**
  → Tearing force = (16 × 9.81 × 85) / 4 = **333**
- **Scale reading: 120, Plies: 8**
  → Tearing force = (16 × 9.81 × 120) / 8 = **23**

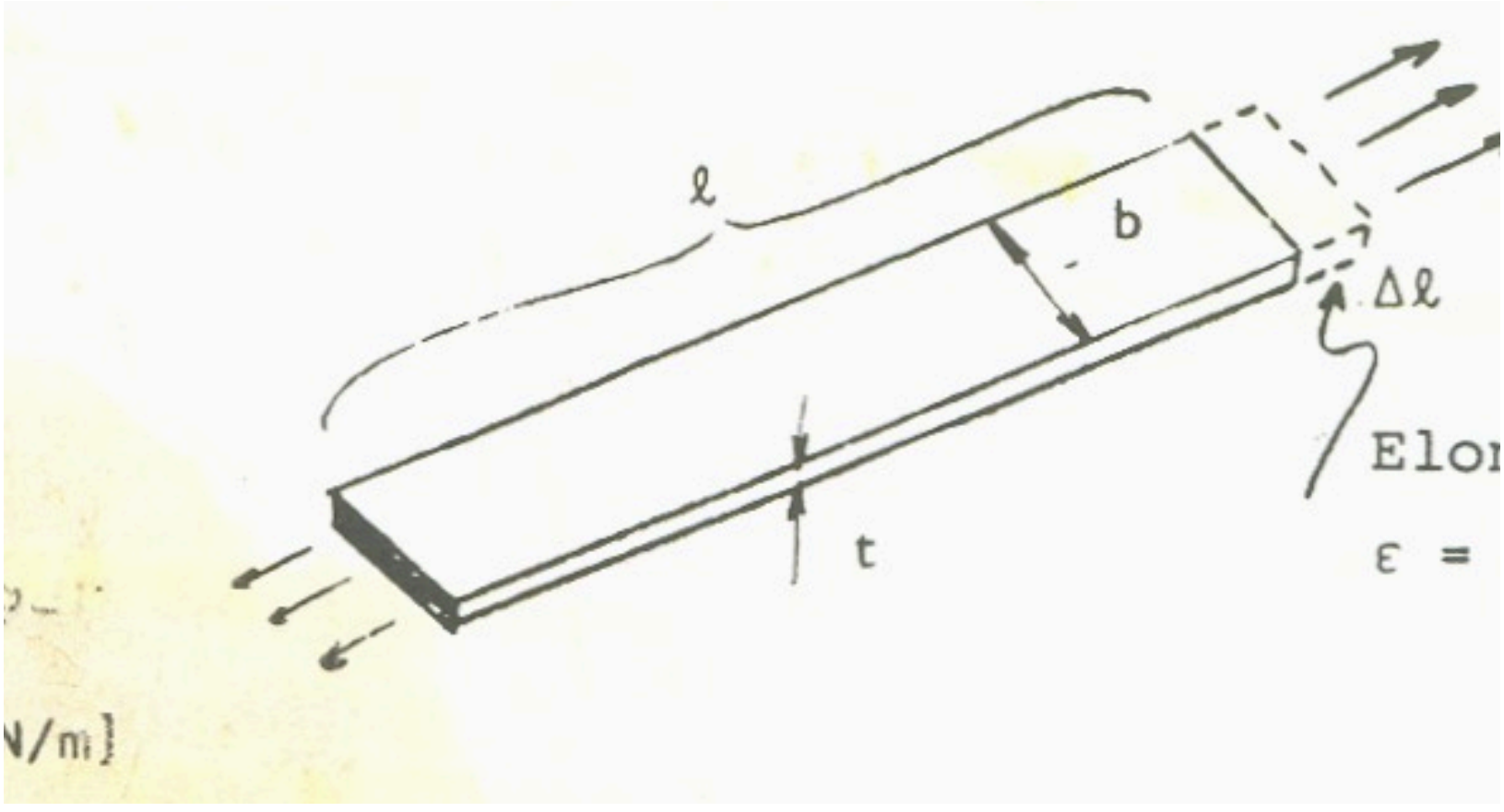
A tear tester

TENSILE STRENGTH OF PAPER:

The force per unit width at rupture is called as Tensile strength.

The tensile index in N/m divided by grammage

The length of a strip of uniform width beyond which, if such a strip were suspended by one end, it would break by its own weight.



Tensile strength = $\frac{\text{kg-force}}{\text{cm}}$

$$= \frac{\text{kgf X 9.80665 X 100}}{\text{m X 1000}}$$

$$= \frac{\text{kgf}}{\text{cm}} \text{ X } 0.980665 = \text{kN/m}$$

Weight per unit length = grammage (G)x length

Breaking length = $\frac{kgf}{15\ mm \times g/m^2}$ (In case of paper thickness is not considered strength is determined force per width)

Since, the load applied in tensile tester is in kg and width of test strip is taken as 15 mm, the load at rupture gives tensile strength in kgf/15mm

$$= \frac{kgf.\ m^2.\ 1000.\ 1000}{15mm.g}$$

$$= \frac{\mathbf{kgf.\ m^2 \times 10^6}}{\mathbf{15\ m.\ kg}} = \mathbf{m}$$

Mass: The Amount of matter in an object is measured in kg

(**Weight:** Force due to gravity acting on a mass, and it changes with gravitational field (e.g., lighter on the Moon)

Weight (W)=Mass (m)×Gravitational acceleration (g) $W=m\times g$

(where $g\approx 9.81\ m/s^2$ on Earth)

Conversion of tensile index into breaking length

Tensile index 1000= Breaking length (m)

$$\text{Breaking length} = \frac{\text{kgf.m}^2}{\text{m.kg}} \text{ or } \frac{9.80665}{1000} = \text{m}$$

(kgf = 9.80665 Newton)

$$\textbf{Tensile index} = \frac{\textbf{N.m. 0.00980665}}{\textbf{g}}$$

Figure 8: Tensile tester

BURSTING STRENGTH OF PAPER:

The maximum hydrostatic pressure required producing rupture of the material when a controlled and constantly increasing pressure is applied through a rubber diaphragm to a circular area 30.5 mm.

Figure 9:

Bursting strength tester

The bursting strength is measured in g/cm^2

One Newton per square meter (N/m^2) = one Pascals (Pa)

One kgf = 9.80665 Newton

Gram force per square centimeter (gf/cm^2) = 98.0665 Pascals

$$\frac{\text{gram force}}{cm^2} \times 100 \times 100 \times 9.80665 = 98.0665 \text{ pascals}$$

$$\frac{}{cm^2 \times 1000}$$

$$= 98.0665/1000 = 0.0980665 \text{ kPa}$$

If bursting strength is in gf/cm^2

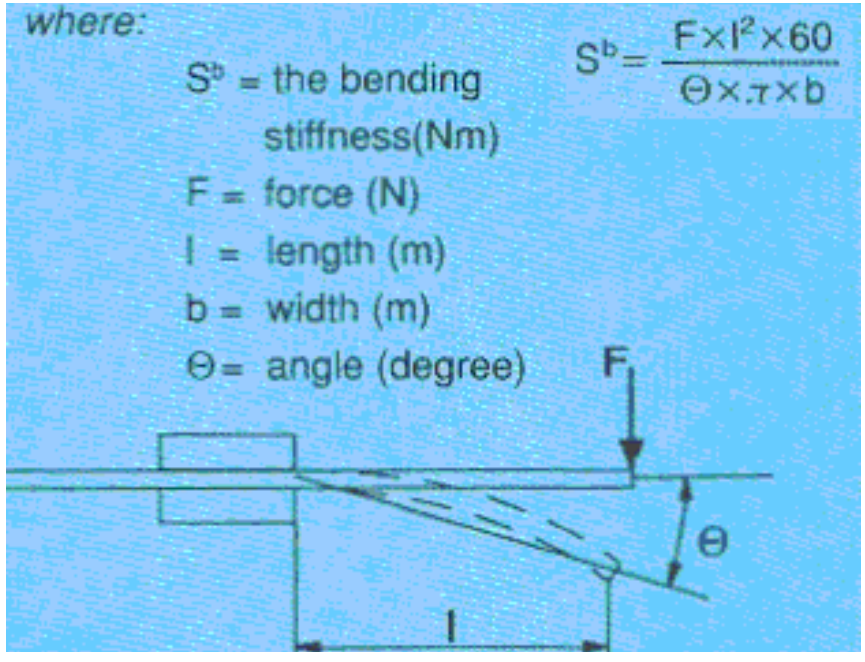
$$\text{Burst index} = \frac{gf \times 0.0980665}{cm^2 / g/m^2} = kPam2/g$$

$$\text{Burst factor} = \frac{gf/cm^2}{g/m^2 \times 100 \times 100}$$

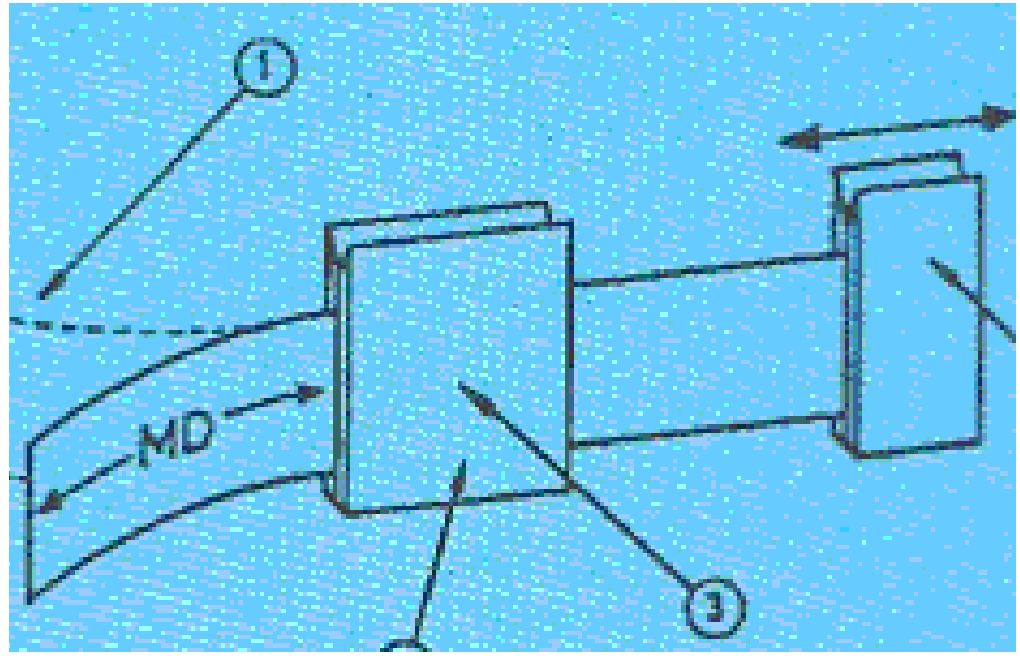
BENDING STIFFNESS OF PAPER:

The degree to which paper or board resists bending when subjected to a bending force in its intended use or when using a defined testing procedure such as the one described in this test method.

One Taber stiffness unit (gram-force centimeters) is equal to 0.0980665 milli Newton meters.



(A)



(B)

Figure 10

(A) Bending stiffness tester (B) Resonance tester

DOUBLE FOLD:

The fold number is the number of double folds the paper can withstand before rupture.

It is the most important property of currency paper and maplitho paper.

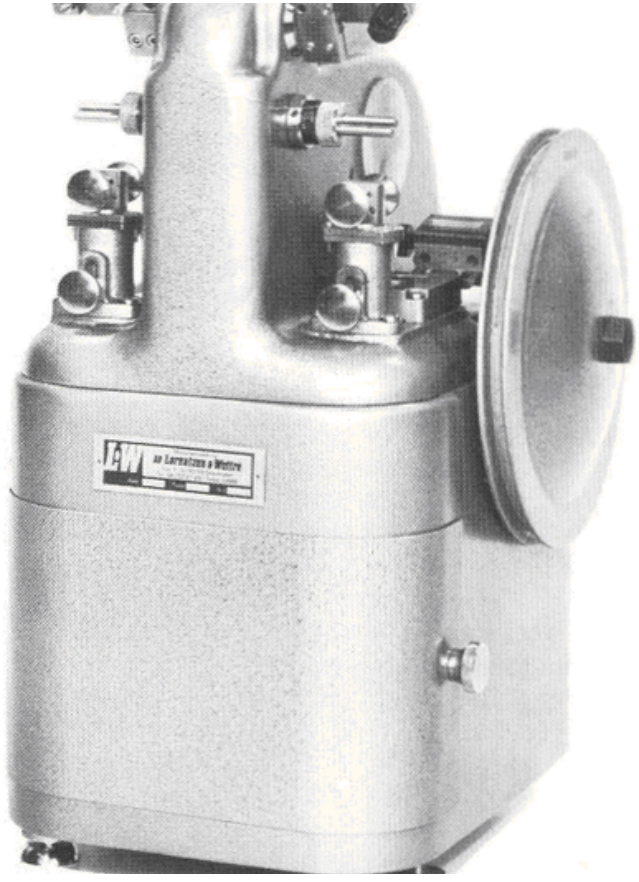


Figure 11: Double fold tester

STRUCTURAL PROPERTIES

Basis weight or Substance or GSM

Justification for the selection of GSM:

Say one was to publish 1000 copies of a book having 100 pages of size 11.8”x8.3”.

The total surface are required for this job will be (1000x100x11.8x8.3 inch^2) = 6108.7 m2.

For this job if he selects paper of basis weight 80 g/m^2 instead of 70g/ m^2.

The total weight of paper for 80 g/m^2 will be 0.49 tones instead of 0.43 tones.

Consider the cost of paper is Rs.40,000/- per tonne. In such case, he has to Pay Rs. 19600/- (higher gsm) instead of Rs. 17,200/- for the same job.

Thus a 100 pages book with higher basis weight paper will be thicker the transportation and postage charges will be increased.

Definition:

Basis weight is defined as the weight in pounds of a selected number of sheets having a specific size. The bunch of this number of sheets is known as "Ream" and the number of sheets as "Ream size".

The weight per unit area of paper-board has been expressed as the weight in pounds per 1000 ft^2.

ISO committee TC6 on paper uses "Substance" ("grammage" in French) for weight per unit area as do the British.

Generally all heavy stiff paper sheets 0.012 inch thick or more other than blotting paper are considered to be paper board.

The term also includes, however, some materials of lesser thickness (0.006-0.012 in.) such as certain liner boards, corrugating material and light weight chip.

Standardization of sheet size:

International organization for standardization has defined A, B, and C series of sizes.

"A" Series Papers :

The surface area of A-0 sheet is 1 square meter

Length of sheet is √2 times the breadth.

Table - 8

Size and area of A-series sheets

Sheet	Dimension	Area
A-0	1190 x 840 mm	1 m^2
A-1	840 x 595 mm	½ m^2
A-2	595 x 420 mm	¼ m^2
A-3	420 x 297.5 mm	1/8 m^2
A-4	297.5 x 210 mm (298 x 210 mm)	1/16 m^2

B Series Papers:

Area of sheet = 1.4 m^2

Length is √2 times the breadth.

Table - 9

Size and Area of B series sheets.

Sheet	Dimension (mm)
B – 0	1000 x 1414
B – 1	707 x 1000
B – 2	500 x 707
B – 3	353 x 500
B – 4	250 x 353

C Series Papers:

Area of C-0 sheet as $1.2m^2$

Lengths are $\sqrt{2}$ times the breadth.

Table – 10

Sizes and area of C-series sheets

Sheet	Dimension (mm)
C – 0	917 x 1297
C – 1	648 x 917
C – 2	458 x 648
C – 3	324 x 458
C – 4	229 x 324

Thickness or Caliper:

The perpendicular distance between to principal surfaces of the paper or paper board or distance between one surface and the other of a sheet of paper or board.

Thickness of a paper sheet or board is also termed as 'Caliper'.

This property is expressed in ‘millimeters’ or micrometers one Millionth of a meter) or thousandths of an inch (i.e. Mils or points).

Caliper (micrometer) = 25.4 x 10^4 x caliper (inches)

= 10^3 caliper (mm)

1 inch = 25.4 millimeters = 25,400 micrometers

Caliper points or mils) = 10^3 caliper inch.

Factors:

Types of fibers

Degree of beating or refining

Pressing or calendaring

Bulk:

The density of paper or paper board is the weight per unit volume or the apparent specific gravity and is usually reported as grams per cubic centimeter

The reciprocal of the apparent density is known as bulk

$$\text{Bulk} = \frac{\text{Thickness (Micrometer)}}{\text{Grammage (g/m}^2\text{)}}$$

Factors:

Types of fibers i.e. thick walled or thin walled

Extent of refining or beating

Use of fillers

Pressing or calendaring

Machine Direction (MD) and Cross Direction:

The machine direction (MD) corresponds to the direction of flow of fibers suspension on the paper machine. The cross direction is at right angles to the machine direction.

Due to orientation of fibers properties will be different (Two sidedness)

Identifications:

Float the specimen on water and note the direction of curl. The axis of curl is parallel to the machine direction of the paper. This method is not generally suited for absorbent papers.

Tear the two strips which are cut along MD & CD. The straight tear indicates the machine direction and CD strip leaves a more ragged edge.

Burst the sample as per Tappi test method T-404. The chief line of rupture will be right angles to the machine direction of paper.

Top and wire side of paper:

The wire side of paper is the side that was in contact with the wire (Fourdrinier) of the paper machine, the other side is termed as 'top side' is generally more rough than top side.

Reasons:

This is due to

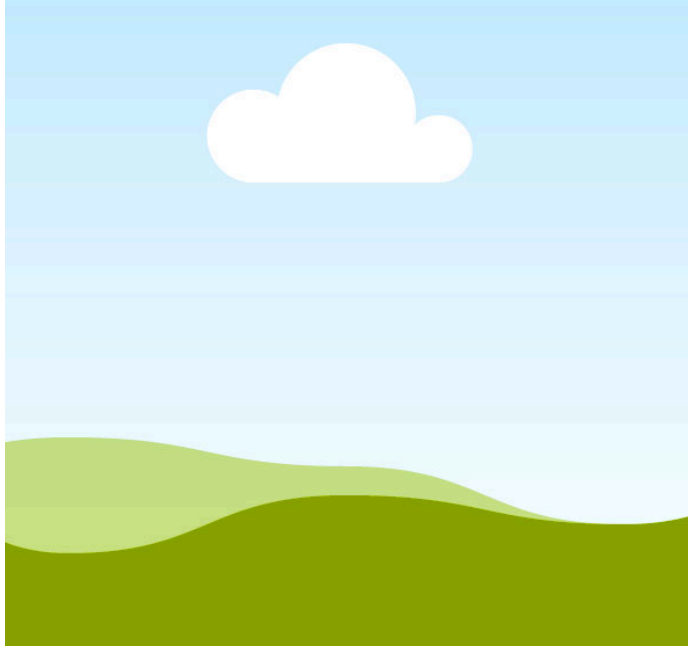
less concentration of fines on wire side than top side.

It may cause difference in brightness, smoothness, porosity, surface strength (wax pick test) and Cobb value

Curl:

Curl is the tendency of paper by itself to bend or partly wrap around the axis of one of its direction

Curl is undesirable for board, card and stiffer papers e.g. photographic paper.



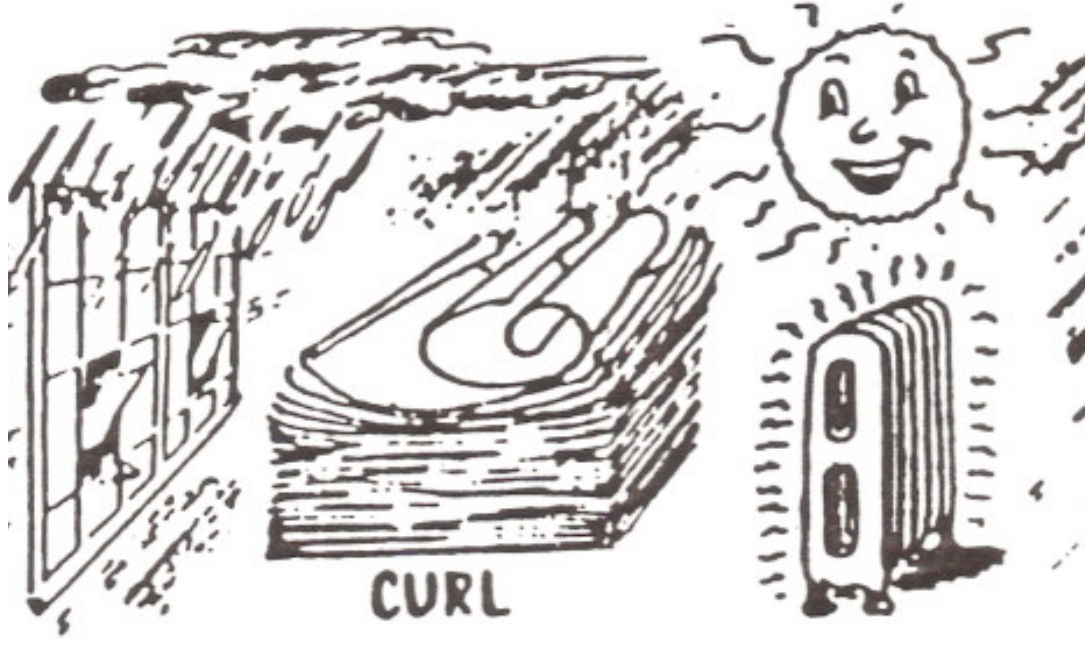


Figure 12: Curling

Reasons:

Orientation of fibres.

Mechanical factors e.g. a sheet stored as a roll for considerable time when sheet is unrolled, curl is observed.

Variations in the moisture content in the sheet.

Curl is more pronounced with thin paper than thick sheet because the former is less stiff.

Porosity:

The interfibre spaces so called capillaries or pores are filled-up with air. Therefore, it becomes porous like foam mattress.

It depends upon: (i) Degree of collapsing of fibers

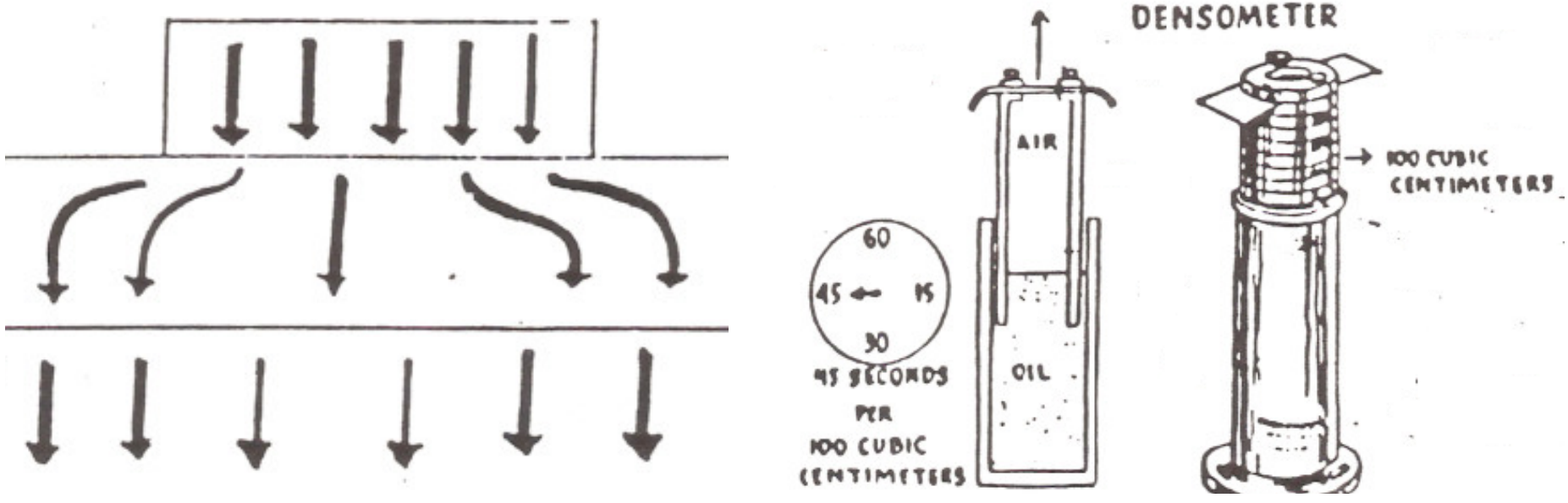


Figure 13

Gurley Porosity test (Schematic)

Time taken to pass 100 ml of air through a one-inch² area

In case of Bendsten tester, paper is sandwiched tightly between two rubber orifices to avoid air leaks through sideways.

Bendtsen Porosity quantifies the volume of air (in ml/min) that passes through a paper or board sample under a specified pressure and test conditions.

Expressed in milliliters per minute (ml/min).

The flow rate of air is the indicator of porosity. Higher test value indicates higher porosity.

Smoothness:

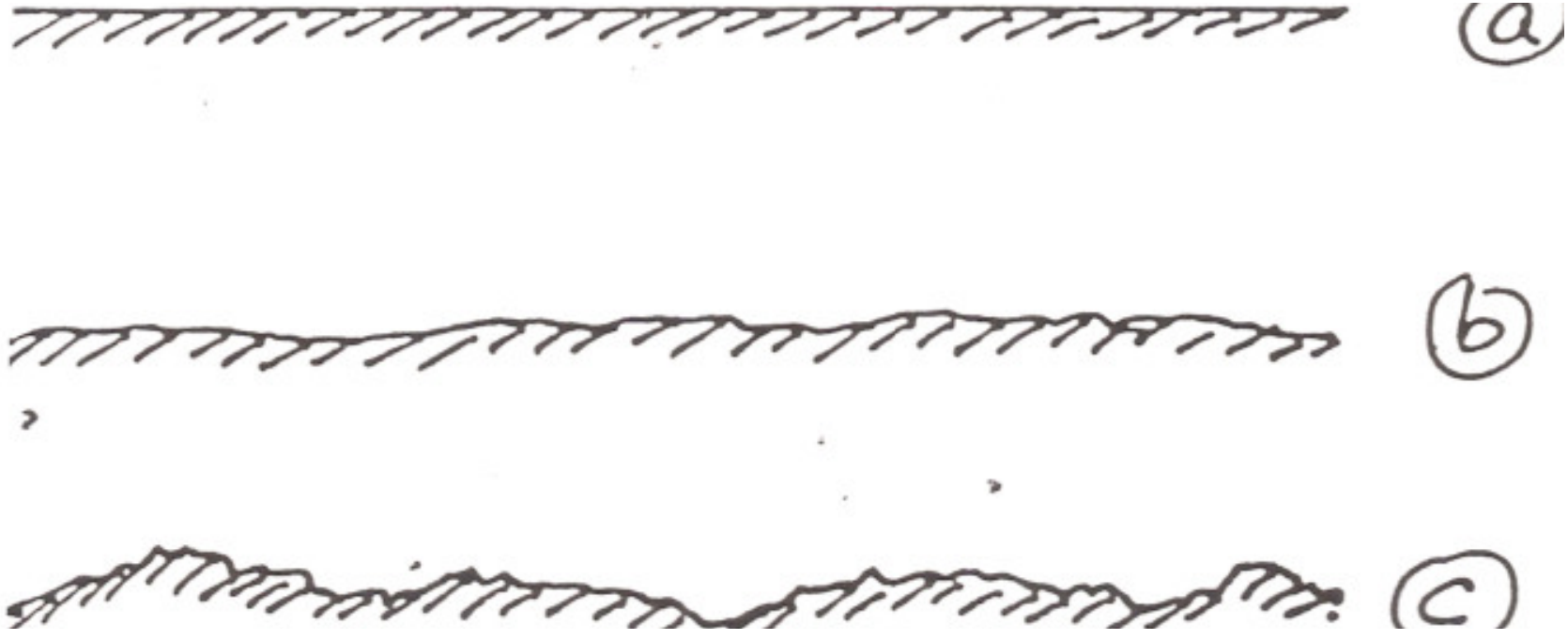
Paper has a smooth or a rough texture meaning that the surface irregularities are small or large.

Factors

Short fibre furnish

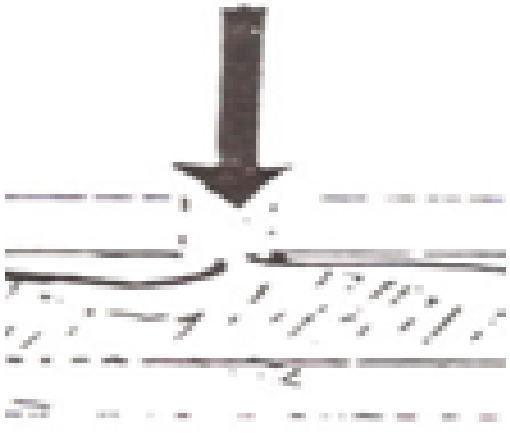
Use of fillers

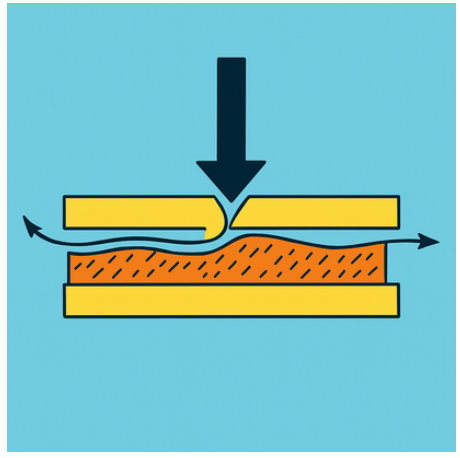
Pressing and calendaring



a= smoothness, b &c rough texture

Bekk Smoothness

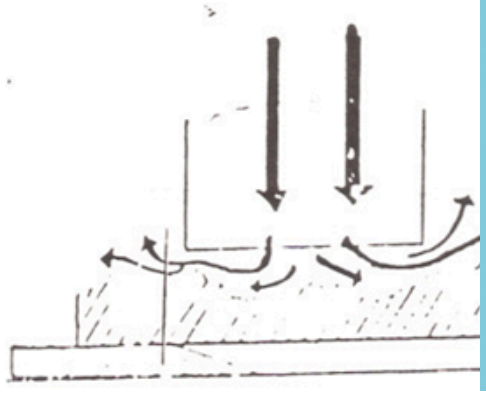


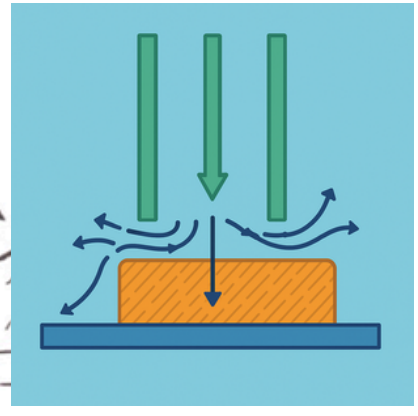


The time (in seconds) for a fixed volume of air (usually 100 ml) to pass through the interface between the paper and the smooth surface.

A higher Bekk smoothness value means the paper surface is smoother because air passes more slowly due to fewer surface irregularities.

Sheffield smoothness





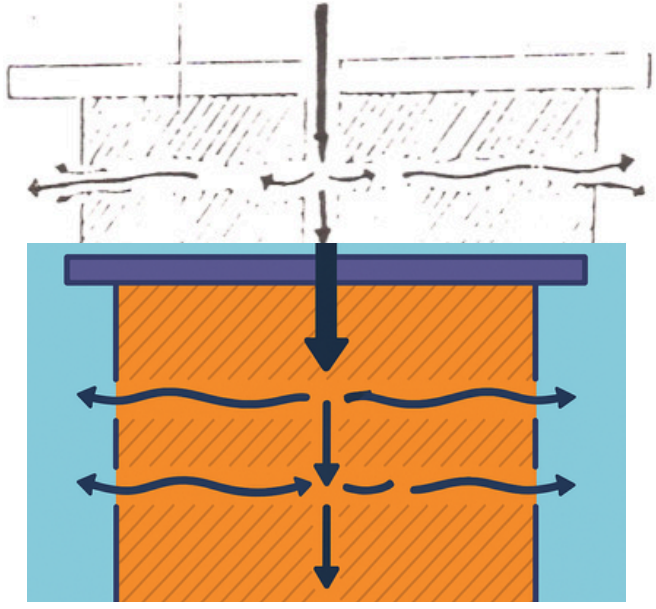
Sheffield Smoothness measures the **rate of air flow** (in **Sheffield units**) between the paper's surface and a smooth, flat metal ring under controlled pressure**.**

Sheffield Units — a flow rate scale based on the volume of air passing through the gap per unit time

Higher Sheffield value → **Rougher** surface (more air passes through)

Lower Sheffield value → **Smoother** surface (less air passes through)

Gurley Smoothness



Gurley smoothness is the **time (in seconds)** required for **10 ml of air** to pass through the narrow gap between a smooth metal ring and the surface of a paper or board sample under standard pressure conditions.

Higher Gurley values indicate a **smoother** paper surface because air passes more slowly through a smaller gap.

Summary of Air-Based Smoothness Tests:

Test Type	What It Measures	Unit	Higher Value Means...
Bekk	Time for air to escape	Seconds	Smoother surface
Gurley	Time for 10 ml air to pass	Seconds	Smoother surface
Sheffield	Air flow rate through surface gap	Sheffield Units	Rougher surface
Bendtsen	Air flow rate (ml/min)	ml/min	Rougher surface

Optical properties

Brightness:

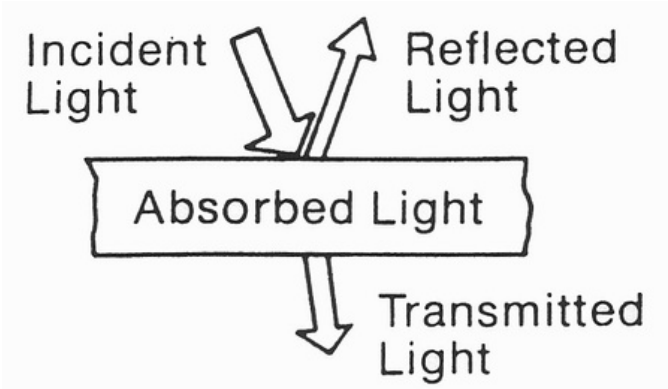
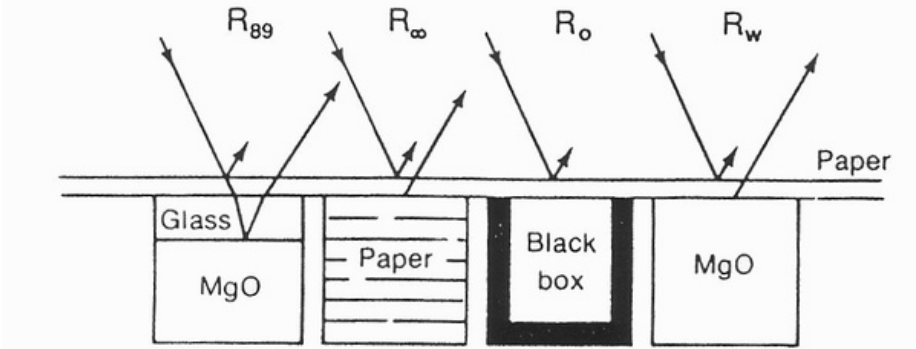


Fig. -2: A schematic illustration of the relationship between incident, reflected, absorbed, and transmitted light

- R_0- the reflectance when a single sheet of specimen is backed by a black cavity.
- R_{00} - the reflectance, made with a backing consisting of an opaque pad (or pad of paper of infinite thickness) of the same paper.
- Rw - the reflectance, made when the backing is a standard white, pure magnesium oxide (MgO) surface and
- R0.89 - the reflectance, when measured with a combined glass of MgO backing having an effective reflectance of 89% of that of pure MgO alone.

Figure - 7: *Light reflectance with four different backings.*



Brightness is determined by the reflectance of a thick pure white magnesium oxide surface under the same conditions, i.e., R_{oo}/R_w at 457 nm.

Opacity

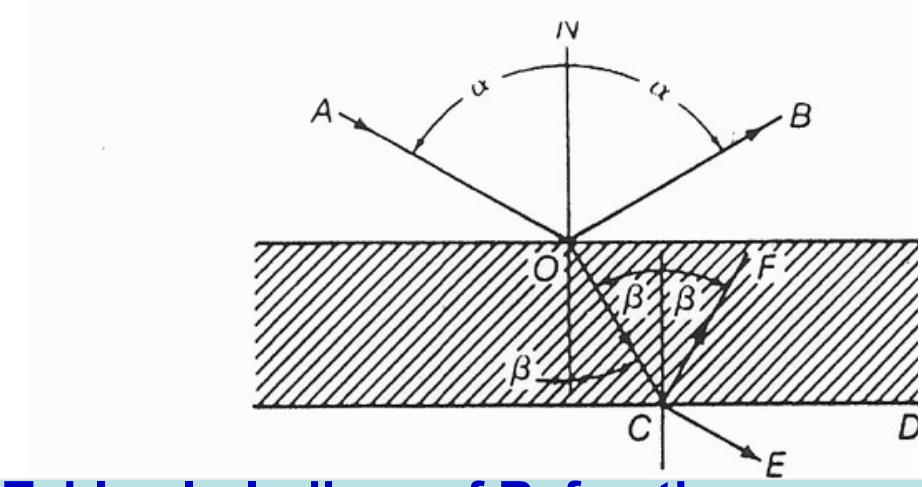


Table - I:- Indices of Refraction

Air	1.00029	China clay	**1.56**
Water@ 20°C	1.333	Barium sulfate	**1.64**
Paraffin wax	1.44	Calcium carbonate	**1.65**
Silica	1.45	Zinc oxide	**2.0**
Starch	1.45-1.53	Zinc sulfide	**2.4**
Calcium sulfate	1.5	Titanium dioxide (anatase)	**2.5**
Glass	1.5-1.59	Titanium dioxide (rutile)	**2.7**
Cellulose*	1.56		
Rosin	**1.55**		

The ideal opacity tester would use a perfectly white body with a reflectance of 100% and a perfectly absorbing body with zero reflectance for the black body.

TAPPI opacity is the ratio of the reflectance of a single sheet backed by the black cavity to the reflectance of the same spot backed by the white body having an effective reflectance of 89%, and it is sometimes designated as C0.89. It can be expressed in equation form as:

$$\text{TAPPI Opacity} = R_0/R0.89$$

Gloss

Specular gloss: light reflected at an angle of 75°

The gloss of waxed paper is determined at 20°.

Sheen: Reflectance is determined at 85°

Contrast gloss is the ratio of the specularly reflected light to the total reflected light, expressed as a percentage

Sl No.	Type of Paper	Tensile Index Nm/g		Brightness ISO[1], Percent	Opacity Percent	One Minute Cobb Test	Double Fold		Gloss[2] Percent	Wax Pick	Smoothness (Bendtsen) ml/min	Tear Index $mN.m^2/g$	
		Min		*Min*	*Min*	*Max*	*Min*		*Min*		*Max*	*Min*	
		CD	MD			Average	CD	MD				CD	MD
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)
i)	Account book	17	25	80	85	25	10	15	-	No pickon 8A	300	4.0	3.5
ii)	Azure laid	17	25	-	85	25	10	15	-	-	280	4.0	3.5
iii)	Bond	25	40	90	90	25	10	15	-	-	350	5.0	4.0
iv)	Cream laid and cream wove/ printing white/ printing coloured/ printing offset	17	25	78	85	25	-	-	-	No pickon 8A	300	4.0	3.5
v)	Printing, maplitho	20	30	82	85	25	10	15	-	No pickon 10A	300	4.0	3.5
vi)	Printing, white super calendered	17	25	80	75	25	-	-	15	-	-	4.0	3.5
vii)	Typewriting	20	25	75	-	25	-	-	-	-	300	4.0	3.5

Sl No.	Type of Paper	Tensile Index Nm/g,		Brightness[1] ISO, Percent	Opacity Percent	One Minute Cobb Test	Double Fold	
		Min		*Min*	*Min*	*Max*	*Min*	
		CD	MD			Average	CD	MD
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
i)	Air mail/ manifold	20	30	80	80	25	-	-
ii)	Cartridge drawing	20	30	80	80	25	10	15
iii)	Cartridge, white	17	25	75	80	25	-	-
iv)	Duplicating absorbent/ Duplicating, semi-absorbent	17	25	72	85	25-70	-	-
v)	Poster, machine glazed	17	25	75	-	25	-	-

Test Method

THANKS