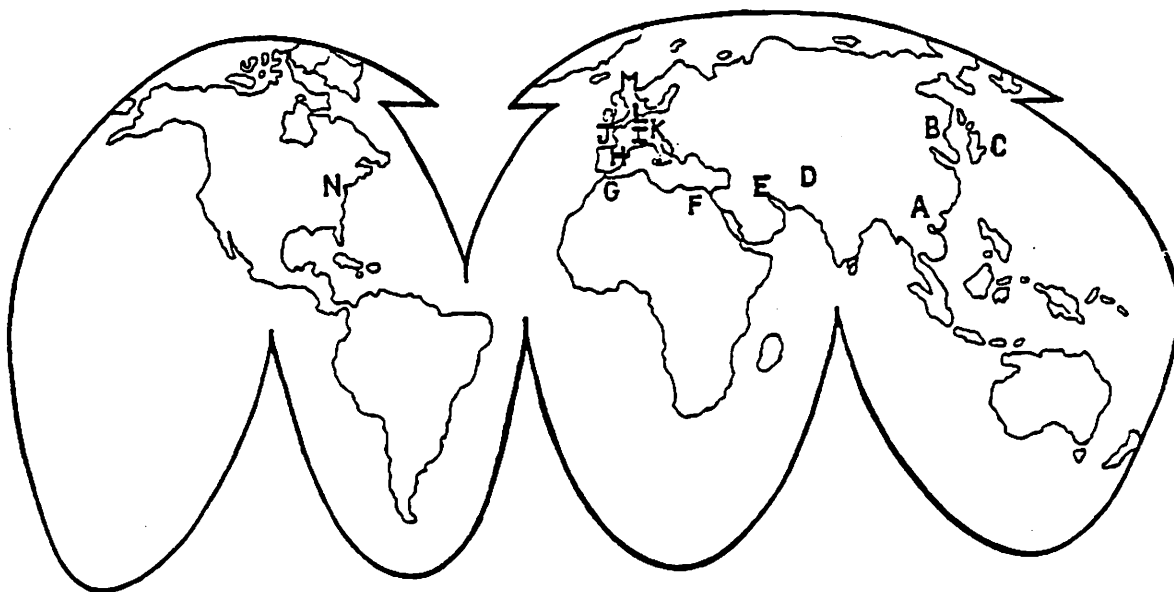


The Remarkable Journey of Handmade Paper from China to the New World



A. Ts'ai Lun credited with the invention of paper in Lei-yang, China, 105 A.D., although many authorities track the invention of paper to, at least, the second century B.C. The art is practiced in Tun-Huang in 150 A.D., in Loulan by 200 and in Niya about 250-300 A.D.

B. The invention reaches Japan via Korea in 610 A.D.

C. Empress Shotoku commissions "The Million Prayers," the first text printing on paper, in 770 A.D.

D. Chinese prisoners of war reveal secrets of paper manufacture to their Arab captors in Samarkand in 751 A.D.

E. The "secret" is carried to Baghdad, where Haroun-al-Rasid has paper manufactured in 793.

F. Egyptians make paper *à la Chinois* in 900.

G. Handmade paper appears in Morocco via Egypt in 1100.

H. Moors first introduce paper to Europe in Xatwa, Spain (the present San Felipe near Valencia) c. 1151.

I. Oldest, uninterrupted paper mill built at Fabriano, Italy in the marquisate of Ancona in 1276.

J. First paper mill established at Troyes, France, c. 1348.

K. Ulman Stromer of Nuremberg sets up first mill in Germany with the assistance of Italian craftsmen in 1390.

L. Hollander machine invented in 1680, superseding all earlier devices including stamping mills and other primitive beating devices.

M. John Tate sets up a paper mill in Hertfordshire, England in the early sixteenth century, although the first mill established in England dates from about 1494. All paper, up to this time, was laid; John Baskerville, wanting a smoother wove paper for his printing in 1754, commissioned the Turkey Mill to produce a quantity for him.

N. Willem Ruddinghuysen van Mulheim (William Rittenhouse) creates the first paper mill in America on the banks of a small stream called Paper Mill Run, which flowed into Wissahickon Creek near Germantown, Pennsylvania in 1690.

- 105 A.D. Papermaking is invented by Ts'ai Lun in the Court of Ho'ti in Lei-yang, China. This first (?) paper is made from hemp, bark, and fish nets.
- 610 Papermaking knowledge reaches Japan through Korea.
- 751 At Samarkand, papermaking is learned by Arabs from Chinese prisoners of war. By good fortune, hemp and flax are grown here in great quantity.
- 763-770 Japanese Empress Shotoku commissions the world's first mass production of one million printed paper prayers, each in a small wooden pagoda.
- 793 Paper is made in Bagdad.
- 900 Chinese style paper is made in Egypt.
- 1100 Paper moves through Egypt and Africa to Fez, Morocco.
- 1151 First papermill in Europe is set up in Moor-occupied Spain at Xativa. A stamping mill is used for beating.
- 1276 Papermaking reaches Italy through Palestine at Fabriano. This mill is still the oldest uninterrupted papermill in the Western world.
- 1348 First mill in France at Troyes.
- 1390 First documented mill in Germany at Nuremburg. A year later, owner Ulman Stromar experiences the first strike of papermill workers.
- 1440-54 Johann Gutenberg invents printing from moveable type in Mainz, Germany. Publishes his first Bible in 1454. Of 200-300 copies. 30-50 were printed on vellum, the rest on paper.
- 1494 First papermill in England, set up by John Tate.
- 1580 First mill in the New World at Culhuacan near Mexico City.
- 1680 or so The 'Hollander' beater is invented in the Netherlands.
- 1690 German William Rittenhouse sets up first papermill in North America outside Philadelphia at Germantown.
- 1729 Benjamin Franklin bankrolls the Ivy Mill outside Philadelphia, the third colonial mill, as part of his active program to establish domestic papermaking for colonial printers and end dependence on Continental paper.
- 1754 English printer John Baskerville commissions the Turkey Mill (Whatman's) outside London to make the first 'wove' paper from a woven wire surface. All paper prior to this was 'laid'.
- 1765-71 Clergyman Dr. Christian Schaeffer of Regensburg, Germany, an amateur scientist, botanist, and 'gentleman papermaker', publishes a six volume study of papermaking from alternative plant and vegetable sources, including many examples of various sheets printed at his house.
- 1774 Bleach is first used to chemically lighten paper fibers. Prior to this, rags and fibers were bleached in the sun or with wood ash solutions.
- 1798 Nicholas-Louis Robert patents the first papermaking machine in France.
- 1800 Matthias Koops of England makes paper entirely from straw and prints a book on it. One edition includes an insert of paper made from wood; the first instance of wood paper. Later, he made paper from recycled printed material and received a patent for it.

A Paper Chronology, 2

- 1803-07 Bryan Donkin of England and Henry and Sealy Fourdrinier of France set up and patent their papermaking machine, the forerunner of all modern continuous web machines at Frogmore, England.
- 1809 John Dickinson patents the cylinder papermaking machine, maker of 'mould-made' papers, in England.
- 1840, 1852,
1884, 1910 Wood pulp processes, mechanical and chemical, are developed and refined. Paper manufacture is greatly increased. Paper quality is greatly decreased.
- 1891 A continuing part of the Arts and Crafts Movement, William Morris establishes the Kelmscott Press in England for the production of fine hand crafted books. Good handmade paper is an integral part of the aesthetic.
- 1928 After working with Elbert Hubbard (who was strongly influenced by Morris) and his Roycrofters in East Aurora, New York, Dard Hunter revives handmade paper in Lime Rock, Connecticut. Hunter spent a lifetime researching the history and practice of paper all over the world. In several of his books, he wrote the text, made the paper, designed, cast, and set the types, printed, bound and published them.
- 1940's Douglass Morse Howell, an artist, poet, and philosopher, begins investigating the artistic uses of the medium of handmade paper, in New York. Working alone, he researched both the scientific and artistic sides of paper. Using only flax or linen and pure water, Howell was 20-30 years ahead of the 'artistic papermaking movement' in doing casting, pulp painting, embedments, multiple couching, and many other techniques. He worked closely with printmaker Michael Ponce de Leon and also trained Lawrence Barker.
- 1963-70 Lawrence Barker teaches papermaking at Cranbrook Art Academy in Michigan. Scores of next-generation papermakers of all sorts were trained; printers, printmakers, sculptural, conceptual, and production papermakers. Walter Hamady, John Koller, Roland Poska, Winifred Lutz are just a few. Some of them, in turn, went on to train or work with more papermakers and artists, leading to the proliferation of the artistic medium today.

A Selection of Terms from Hand Papermaking

- Paper - an aqueous deposit of beaten vegetable fibers in the form of a sheet or a web.
- Abaca - also called manila or manila hemp, this fiber comes from the stalks of a tree closely related to the banana, Musa Textilis. Available in the form of rope or sheets of processed fibers, it is grown and processed in the Philippines.
- Agave - any number of related plants of the amaryllis family, especially the century plant of American deserts, having tall flower stalks growing from fleshy leaves. Sisal and tequila come from different agaves.
- Alum - aluminum sulfate or hydrated potassium aluminum sulfate, called 'papermaker's alum', not to be confused with cooking alum. It is used to precipitate rosin size or for mordanting certain dyes. If not removed, its high acidity will eventually damage the paper.
- Ass - a notched piece of wood on the bridge of the vat against which the mould is propped up to drain.
- Bast - fibers from the inner bark of the stems or trunks of certain plants. Flax, kozo, gampi, hemp, ramie, and mitsumata yield long, strong bast fibers.
- Blister - a paper defect usually caused by an air bubble between the felt and the sheet.
- Bonding - the inherent ability of cellulose fibers to be drawn to and adhere to one another through hydrogen bonding to become paper. Fibrillation, hydration, pressing, and drying all promote bonding.
- Bridge - a board across the back of the vat on which the mould is placed.
- Buffering agent - an alkaline substance, usually calcium carbonate or magnesium carbonate, added to the pulp to raise the pH and to protect the paper from exposure to acidity in the environment. Some water supplies are naturally buffered.
- Calendering - the process of passing paper through a pair or series of rollers, or between metal plates in a press, to give a smooth finish to the paper. If the plates or rollers are heated, the resulting paper is called 'hot press.'
- Cellulose - the long-chain organic molecule which forms strong plant cells called fibers. Cellulose fibers are the raw material of paper.
- Cloudy - an unevenly formed sheet of paper, most apparent when held up to light.
- Cockling - a wavy effect, usually on the edges of a sheet of paper, caused by uneven drying. Some fibers and some pulps tend to cockle more than others.
- Contraries - unwanted specks, chunks, fibers, or foreign material in the pulp that turn up in the finished sheets.
- Cotton - nature's most pure form of cellulose fibers (98%) is located in the seed hairs of this plant. After ginning, long fibers are used in textiles. Shorter fibers, called linters, are cut from the seed and used in papermaking.
- Couch - the transfer of the newly formed sheet of wet pulp from the mould surface to a dampened felt. Pronounced kooch.

Dead beaten - overbeaten stock made into a sheet which is weak and lifeless.

Deckle - a removable frame that fits over the mould to form a rim around the screen area. It contains the pulp during sheetforming and defines the shape and size of the finished sheet of paper.

Deckle edge - the uneven edge of a sheet of paper formed by pulp meeting the deckle's 'fence' and, sometimes, a small amount of pulp washing under. Handmades have four natural deckles; mouldmades have two; some machine-mades have two.

Feathered edge - exaggerated deckle edge formed by a gap between the deckle and the surface of the mould. Can be intentional.

Fibrillation - the bruising and shredding of the fibers during beating. It increases the surface area to promote hydration and bonding.

Flax - a bast fiber plant, yielding one of the longest and toughest fibers for papermaking. Produces crisp, slightly translucent paper which is strong and resists wear. Textile flax is linen. Used linen rags generally make a fine paper.

Flocculation - the 'clumping' of fiber groups in pulp suspensions caused by physical entanglements and weak attraction between hydrated molecules.

Formation - the evenness of fiber distribution in the sheet when held to the light. A very even sheet is said to have a "close" formation.

Foxing - yellowish/brownish stains in paper generally caused by the presence of iron particles or ions. Iron contamination in any part of the papermaking process, including the water supply, can cause the discoloration to appear, sometimes years after the paper has been made and printed. Spots may also result from bacterial action.

Free - property of pulp that drains quickly on the mould after dipping.

Furnish - the particular mixture of fiber, water, and other materials that comprise a pulp from which paper is made.

Grain - an orientation of fibers in machine-made paper which allows easy tearing in one direction. Handmade and mouldmade papers have no grain, although some handmades, especially Japanese style, may have a grain if a shake in one direction predominates at the vat.

Half-stuff - half-beaten stock (usually from new cotton rag) available from some mills. It requires further beating in a hollander.

Hemi-cellulose - straight-chain polymers of sugar other than glucose (the polymer building block of cellulose) found in varying proportions in plants. The presence of some hemi-cellulose aids in the beating of cellulose fibers, but too much produces a weak paper.

Hemp - a bast fiber plant, Cannabis sativa, found throughout the world, which yields a long, strong fiber for ropes, textiles, and paper.

Hog - a slow-moving mechanical agitator used to keep pulp from settling in the vat.

Hollander - beating machine invented ca. 1680 in the Netherlands (hence the name). Circulates water and rags in an oval with a bladed beater roll on one side.

Hydration - also called imbibition. The absorption and attraction of water molecules to the cellulose molecule as the result of beating and fibrillation which causes it to swell with water.

Jute - an Indian fiber plant, Corchorus capsularis, with a short but useful fiber used for twine, burlap material, and papermaking.

Knots - small clots or tangles of long fibers that create lumps or spots of density in the sheet that can be very hard. Can be caused by unbeaten or underbeaten fiber in the pulp, by jams in the beating, or by 'pinching' the pulp.

Knotter - an agitated strainer containing plates with holes or slots of specific sizes to strain out knots and other lumps before the pulp goes to the vat.

Laid - the mould surface which is made up of closely spaced wires laid parallel to each other (usually from 18 to 32 lines per inch) and held in place by widely spaced (from 1" to 2") perpendicular chain wires or threads which are twisted around each wire and tied to the mould supports. Paper made on such a surface is 'laid' paper. The pattern is visible when held against the light.

Lignins - nonfibrous polymers that bind cellulose fibers together in living plants. Lignins reject water and must be removed before beating.

Linters - the short fibers that remain on the cotton seed after the first ginning. They are too short for textiles and are removed in a cutting process, matted together in sheets and sold to papermakers. The sheets are also called linters.

Loading - the addition of materials like clays and minerals to pulp to fill the spaces between fibers in the sheet, to increase opacity, weight, ink reception, and surface smoothness.

Machine-made - paper made on a high speed continuous fourdrinier machine. Such paper is made in a web, has a grain, and is usually of wood pulp.

Mould - a wooden frame over which is stretched or attached a porous screen or cloth. Used for making a sheet of paper by draining water from a dipped mat of pulp.

Mould-made - paper made on a cylinder machine, resembling handmade paper, but usually having two natural deckles and two torn or wire deckles. The name is a misnomer.

Pinch - to squeeze a small quantity of pulp together tightly between the fingers or between a stopper and drainpipe, bucket and scoop, etc. The pinched fibers will stay together and cause a knot.

Post - a pile of freshly couched sheets of pulp alternated with felts, which is ready for pressing.

Pulp - the aqueous suspension of refined or beaten fibrous material from which paper is made.

Rag - term used to describe the fiber content of paper. It is generally taken to mean pulp derived from beaten rags of cotton or linen, or occasionally other natural fibers made into cloth. With some mills, it may also mean cotton linters, as in many art papers called 'rag,' or also the presence of hamp, jute, manila, or even sisal or ramie - in fact, practically any other fiber other than wood

Rattle - the sound, made by shaking a sheet of paper by one corner, that indicates its rigidity, stiffness, crispness, sizing, and is a measure of its quality.

Retention agent - a liquid additive to pulp which promotes weak electrical attractions between fibers and fine particular additives, such as pigments, loadings, or liquid dyes. More material can be retained in the pulp, resulting in more efficient coloring, buffering, and so on.

Shake - the vatman's stroke in pulling the mould up from the vat and forming the sheet of paper. The movement goes from right to left, left to right, and from the body away to the vat, casting off excess pulp. It misaligns the fibers in a sheet of handmade, producing a strong sheet with no grain.

Sisal - useful fiber derived from the Agave sisalana species of agave plant in Mexico or Africa and usually found as cordage.

Sizing - a water-resistant material added to paper to coat the fibers and make them less absorbant and to fill in the spaces between the fibers to aid in achieving a smoother surface, which promotes a better ink layer in the printed sheet. Also stiffens the sheet and some sizes increase the rattle. Sizing added before sheetforming, in the beater or the vat, is called 'internal sizing.' Sizing added after the sheet is formed, usually after it has been dried, is called 'tub sizing' or 'surface sizing.'

Slurry - the thinned or diluted stock in the vat which is the proper mixture and proportion for sheetforming.

Snowstorm - term used to describe the formation of a wild, flocculated sheet.

Spur - a group of sheets (usually 3 or 5) picked from a pressed pack of sheets and placed to dry. Regardless of the drying method, the position of the sheets in the spur is changed once or twice a day.

Stay - platform perpendicular with the bridge on which the vatman places the newly-dipped mould to drain.

Stock - usually, pulp ready to be made into sheets. Also, pulp at any stage.

Stuff - untreated pulp, ready to be made into waterleaf or to have sizing and other additives added.

Vatman's tears - or 'drops' - drops of water that fall on a newly formed sheet from the vatman's arms or hands, from the deckle when it is removed, or from the coucher's hands. They disrupt the lay of fibers and leave a defect of thickness visible when the sheet is held to light.

Waterleaf - unsized paper.

Watermark - usually, a line design in paper, visible when the sheet is held up to the light, caused by bent wires mounted on the surface of the mould which result in a thinner layer of pulp in that spot, showing the design. It actually has nothing to do with water and the name is a misnomer.

Web - a continuous sheet of paper made on a fourdrinier style machine.

Wet - property of pulp that drains very slowly on the mould after dipping.

Wild - term used to describe a very uneven formation or distribution of pulp in a sheet of paper. More uneven than cloudy.

Wove - the mould surface which is made from a woven mesh of brass, bronze, copper wire or of a synthetic material like polyester that is very rigid. Paper made on such a mould is called 'wove' paper and displays no pattern of lines of any kind when held to the light. Its surface is also smoother, owing to the very even distribution, which makes it desirable for some printing processes.

Yucca - plant of the lily family having stiff pointed leaves, found in the Southwestern U. S. and Latin America. Yields a long leaf fiber which was most useful to native cultures and may be used for papermaking.

Some Japanese Papermaking Terms

Kozo, mitsumata, and gampi - small native Japanese trees whose bast fibers are long, supple, and strong. These fibers are the basis for Japanese papermaking.

Chiri - term for unwanted bits or flecks of bark in the paper. Paper which is intentionally made with these flecks is called chiri or chirigami.

Dispersion agent - a vat additive with an eggwhite-like consistency which keeps long fibers from tangling, allowing thin, even sheets to be made. Often called neri.

Geta - the hinged frame of a Japanese mould which holds the su.

Su - the removable, flexible screen surface of a Japanese paper mould. It is usually composed of a laid surface of thin bamboo strips tied together with special silk thread. The complete mould and screen is called the sugeta.

Sha - a finely woven silk cloth placed over the su for the purpose of creating a thin Japanese paper without the bamboo 'laid' pattern. Generally treated with persimmon juice before use. May also hold a watermark.

Tororo-aoi - Japanese name for a plant, *Abelmoschus manihot*, of the hibiscus family. Its roots are boiled and strained to produce neri.

CHAPTER 2

COMPOSITION AND STRUCTURE OF PAPERMAKING FIBRES AND THE EFFECT ON THESE OF THE BEATING PROCESS

H. W. EMERTON

1. FIBRE COMPOSITION AND STRUCTURE

Since its inception nearly 1900 years ago, paper, in the common sense of the word, has been made from vegetable fibres. The origin of the word fibre is unknown, but it has long been used to denote those plant cells the length of which greatly exceeds their transverse dimensions. In this chapter, we shall consider the chemical nature and physical structure of the fibres more commonly used for papermaking.

Vegetable fibres, although containing (usually in small quantities) a wide range of other substances, are largely composed of so-called plant cellulose. The chief constituents of this are associated chemically in such a way that their rationalisation is somewhat arbitrary and no precise meaning can be attached to many of the terms employed. The classification usually adopted nowadays is illustrated in Fig. 3. The first sub-division distinguishes between

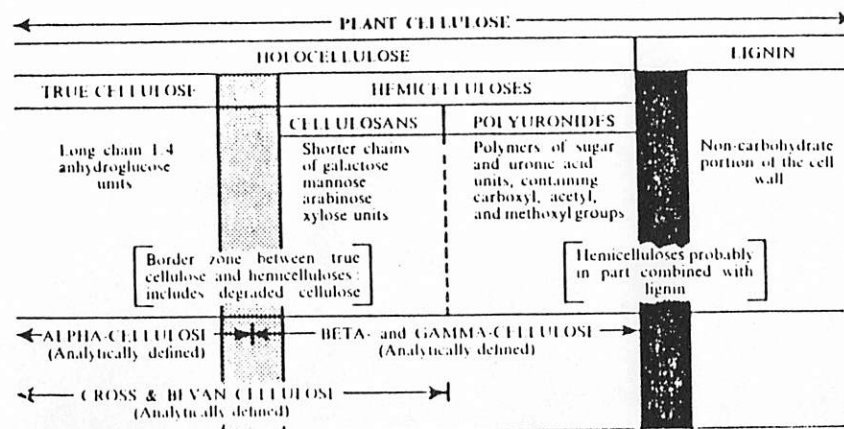


FIG. 3. Classification of plant cellulose

"Fundamentals of the Beating Process", H. W. Emerton (British Paper & Board Industry Research Association, Kenley, 1957)

holocellulose and lignin, the former comprising cellulose and a group of other polysaccharides known collectively as hemicelluloses. Cellulose, hemicellulose and lignin are thus the major components, but associated with these are pectic substances, fats, waxes, gums, mucilages, starch, protein residues and many other organic compounds of great complexity, as well as mineral matter. Except in so far as their presence may detract from the desired paper-making properties of the fibres, these are of no interest to the papermaker.

Of the three major constituents, cellulose is essential, while the hemicelluloses are to some extent beneficial for the paper to be made from the fibres. Lignin, on the other hand, is detrimental and its removal from within and between the fibres is the object of digestion and, to a large extent, of bleaching. The relative amounts of these major constituents are shown in Table 1.

TABLE 1
AMOUNTS OF THE CHIEF CONSTITUENTS OF PAPERMAKING FIBRES
(DRY BASIS)

Papermaking Material	Alpha-cellulose (%)	Hemicelluloses and other non-cellulosic polysaccharides (%)	Lignin (%)
Wood	40-50	12-31	20-30
Raw cotton	88-96	Up to 6 (mainly pectin)	None
Linen rags	92-96	1-3	3-5
Flax	65-70	15-21	2-5
Esparto grass	44-50	26-30	16-19
Cereal straw	31-40	35-48	15-25

The cellulose content is highest in cotton, which, after the extraction of wax and pectin, is almost pure cellulose, in which form it is usually used for papermaking. In other cases, notably cereal straw, it may amount to less than half of the dry weight of the raw fibre.

TABLE 4. THE DIMENSIONS OF SOME PAPERMAKING FIBRES

Source of fibre	Elongated cells		Short cells		Length/breadth ratio	
	length (mm)	breadth (μ)	length (μ)	breadth (μ)	elongated cells (tracheids and fibres)	short cells
Pine	2.0-3.0	22-50			60-90	
Spruce	3.1-3.5	19-50			70-160	
Poplar	1-5	25	650	100	60	6-5
Esparto	1-5	11	10-60	10-50	136	3-6
Cereal straw	1-5	13	120-600	7-60	115	3-16
Manila	1.8-6.2	11-18	90	25	254	4
Sisal	1.3-2.7	19-37	12-15	18-13	35-112	3-7
Cotton linters	2-12	20			100-600	
Cotton fibres	12-50	9-23			1000-4000	
Flax	10-36	11-20			1100-1200	

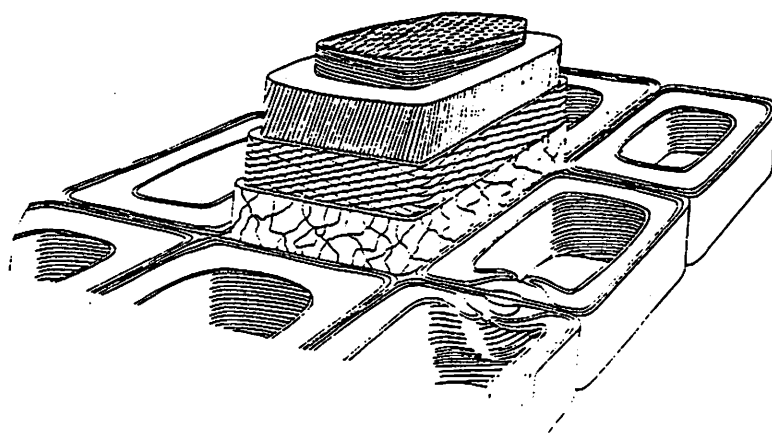


FIG. 11. a) Wall structure of tracheids—perspective view (the coxial lamellae of S2 are omitted for clarity).

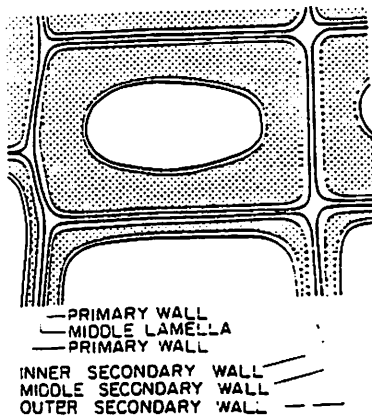


FIG. 11. b) Wall structure of tracheids, transverse section (Kerr and Bailey)
"Fundamentals of the Beating Process", H. W. Emerton British Paper & Board Industry
Research Association, Kenley, 1957)

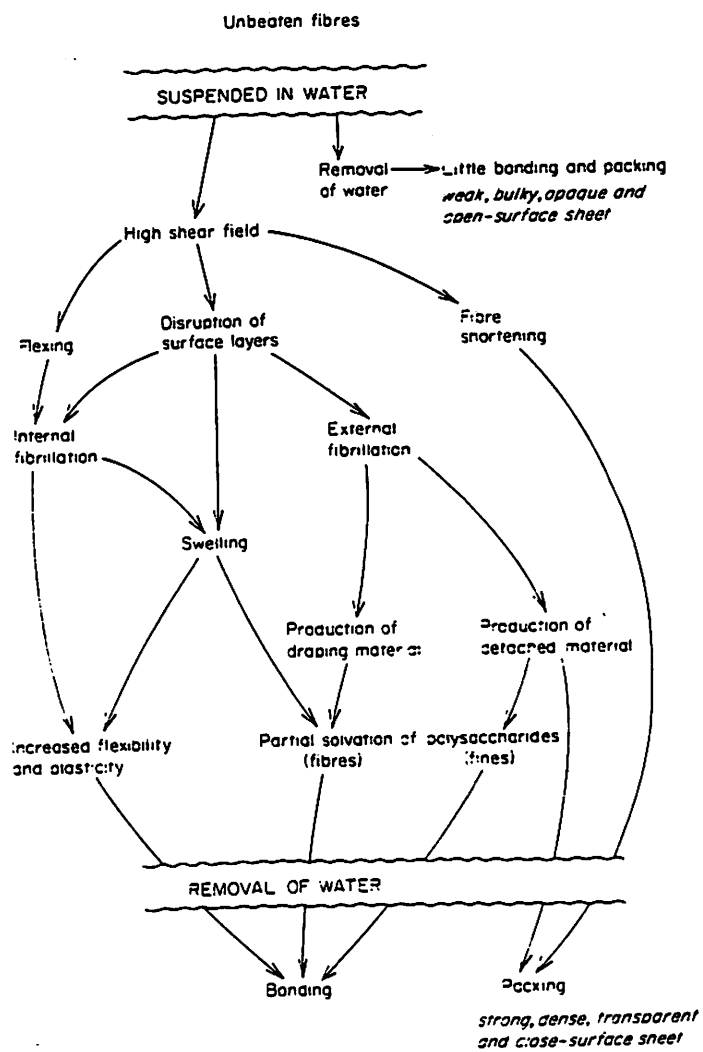


Fig. 3.2. Scheme of the beating process.

Instructions for using the small 1½-pound Valley beater

1. Check beater for cleanliness. Hose out once under the beater roll and rinse the tub. If you are beating a batch of pure white or other special pulp, you may want to fill it with water, turn it on briefly, and drain. Check for free movement of the beater roll. Inspect visually for anything 'different.'
2. Start with no weight on the rod.
3. Fill with water to 1½" of the top edge of the inflow area.
4. Turn on beater and add about 3-4 oz. of rags or other material. Add slowly so that there are no clumps going through and so that clumps do not block the outflow area.
5. Put on the medium weight and continue adding. The weight will jump.
6. Continue adding until about 8 oz. or more are in. Change the medium weight for the heavy weight.
7. Continue adding until your material is used up or until the bulk of the material in the beater feels full and it fluffs up above the water level. The capacity of the beater is 24 oz., but a full load will generally be achieved with about 16-20 oz. of fiber material.
8. As the fiber in the beater begins to absorb water, the water level will drop lower than when begun. Add water to bring the level back up to about 1" of the top edge of the inflow area. Watch the outflow water level to avoid overfilling.
9. Beat for about 10-40 minutes with the heavy weight, then about 10-30 minutes with the medium weight, then about 10 minutes with the light weight, then about 10 minutes with no weight.
These times are approximate, depending on the particular material being beaten, the amount of material in the beater, and the nature of the finished pulp desired. Generally, use the heavy weight until all banging and clanging has ceased and no more 'weave' or clumps are seen plus a few minutes.
Also, in general: more water + less fiber = short fibered pulp
more fiber = less water = long fibered pulp
10. Check the progress of the pulp often with a glass jar and water. Look for 'freeness' of the fibers - lack of clumpiness - and the cloudiness of short fiber dispersion. Keep a written record of each batch of pulp for quantities of ingredients, times of weights, etc. Check the feel of the pulp often with your fingers. Note the onset of the perception of slipperiness of the pulp toward the end, or when the pulp clings stubbornly to your skin, and continue clear beating for some time after.
11. When beating has been satisfactorily completed, drain pulp carefully without pinching into clean buckets and clean barrels. A full beater produces about 6 gallons of pulp.
12. Wash down beater thoroughly, especially under beater roll and along its sides. Spray hard with lots of water from many angles until no more pulp or weave appears in the wash water. Wipe down, insided and out, with sponge. Wipe beater base and motor area. Remove water from the floor with the wet-vac.

Instructions for using the large, 5-pound Noble & Wood beater

1. Check beater for cleanliness. Check for free movement of the beater roll.
2. Start with the lever swung away over towards the wall, raising the roll.
3. Place buckets under the drain hole and roll area to catch water which leaks while beater is being filled and early in beating. Fill beater with water up to about 2" of the top edge of the inflow area.
4. Turn beater on and add at least two pounds of rags, linter, or other fiber.
5. Pull lever from wall position to machine position, about 180°, lowering roll, but still giving relatively free flow.
6. Continue adding material until most is used up or until the bulk of material in the water feels full when you squeeze it with your hand.
7. Turn handle counter clockwise until the beating sound tells you that the clearance is very small and 'heavy weight' beating is occurring.
8. Finish adding material. Additional water may be necessary to bring water level up to about 1½" of the top edge of the inflow area.
9. Beating times will vary greatly with this beater, depending on the material, amount in beater, and desired pulp quality. The dirty brown linter will take heavy beating for about an hour. Rags will take longer, most alternative fibers shorter. Medium beating should take roughly an hour and clear beating half an hour more.
10. Check progress of the pulp often with a glass jar and water. Look for freeness of fibers - lack of clumpiness - and the cloudiness of short fiber dispersion. Keep a written record of each batch of pulp for quantities of ingredients, times of beating clearances, etc. Check the feel of the pulp often with your fingers.
11. When beating has been satisfactorily completed, drain pulp carefully without pinching into clean buckets and a clean barrel. The full beater will produce about 20 gallons of pulp.
12. Wash down beater thoroughly, especially under the beater roll and along its sides. Spray hard with lots of water from many angles until no more fiber appears in the wash water. Lift the wooden roll cover off for easier access - careful, it's heavy. Wipe down, inside and out, with a sponge. Remove excess water from the floor underneath with the wet-vac.
13. Be sure to leave the lever swung around toward the wall and to turn the handle back to raise the roll to the open roll position.

from A Handbook of Papermaking, by Robert R. A. Higham,
Business Books Ltd., 1963

1.3 fibre types

Table 1.2 lists fibre dimensions. This table, together with the short descriptions of the various fibres and relevant drawings, should be sufficient to enable the reader to recognize the commoner types of fibres.

Table 1.2. COMMON FIBRE DIMENSIONS

Fibre	Length in mm	Average length mm	Width mm
Cotton	10-60	18	0.020
Bagasse	1-8	13	0.030
Flax	5-36	25-30	0.012-0.027
Hemp	6-65	20	0.025-0.050
Manila hemp	2.5-12	6	0.025-0.040
Bamboo	1.5-4	2.5	0.025-0.040
Esparto	0.5-2	1.5	0.013
Cereal straws	1-3.4	1.5	0.023
Jute	1.5-5	2	0.02
Hardwoods	1-1.8		0.03
Softwoods	3.5-5		0.025
Poplar (aspen)	1-25		0.025-0.030
Reeds	0.6-1		0.012

1.3.1 CHARACTERISTICS OF THE MAIN PAPERMAKING FIBRES

On the basis of their location in the plant, papermaking fibres may be divided into five separate categories:

Seed hairs: cotton
 Bast fibres: flax (linen), hemp, jute, ramie
 Leaf fibres: esparto,* manila, sisal
 Wood fibres: softwoods and hardwoods
 Grasses: cereal straws, bamboo, bagasse (sugarcane)

* occasionally grouped as a grass

1.3.1.1 COTTON (Fig. 1.5)

A long, twisted ribbon-like fibre (approximately 150-300 twists per in) often showing criss-cross markings. The lumen is usually prominent owing to the thin transparent cell wall. There are no associated structures and the fibre contains the highest quantity of cellulose of all the natural fibres, i.e., about 95%. There is no lignin present.

It is normal in papermaking to use only the short-fibred linters from the plant, the majority of the long "staple" fibres being used in the textile industry.

1.3.1.2 FLAX (linen) (Fig. 1.6)

The individual fibre is long and the ends have a tendency to be pointed. There are dark nodal areas and the cell wall is usually thick and rather opaque. The lumen is narrow and indistinct and there are fine transverse striations across the fibre. There are no associated structures present, but non-cellulosic material is often found. The fibre is strong, tough and easily fibrillated. The cellulose content is in the region of 70%, and lignin 2-5%.

1.3.1.3 HEMP

A similar fibre to flax with thick cell wall and striated markings. It contains non-cellulosic material, together with lignin. The cellulose content is about 77%.

1.3.1.4 JUTE

A fibre of regular width with tapered ends, and generally a clear lumen. It contains lignin and only approximately 60% cellulose. Note that the presence of lignin makes bleaching difficult.

1.3.1.5 ESPARTO (Figs. 1.7a, b, c)

A slender, cylindrical fibre with tapered ends and a fine indistinct lumen due to the natural opacity of the fibre. Esparto pulp often contains



Figure 1.5.
COTTON FIBRE

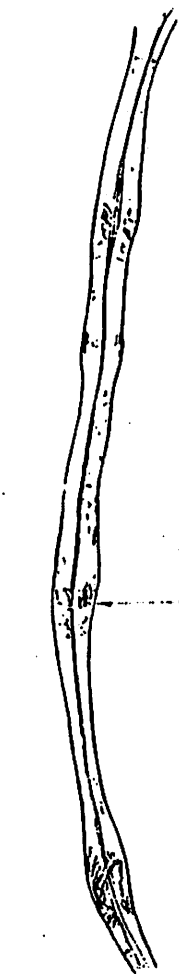


Figure 1.6.
FLAX (linen)
Portion of bast fibre with thin lumen. (a) Nodelike bulges in cell wall due to processing

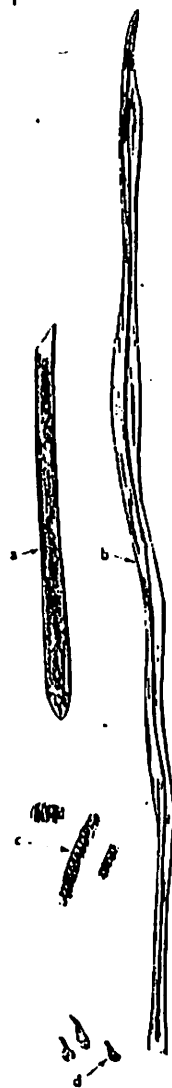


Figure 1.7(a)
ESPARTO FIBRE
(a) Pitted vessel element. (b) Fibre (c) Short tracheid like cell. (d) Epidermal hair.

the following associated fibre structures:

- Epidermal cells with serrated edges,
- Epidermal hairs (trichomes).
- Pitted vessel elements.

Cellulose content of the fibres varies according to the origin of the plant, but is generally around 46-58%, with lignin at 16-19%.

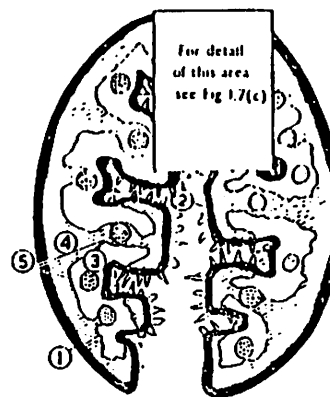


Figure 1.7(b). CROSS-SECTION OF ESPARTO LEAF (magnified 200 times)
(1) Epidermis. (2) Epidermal hair cells — "commas". (3) Parenchymal cells (4) Fibres (5) Vascular bundles.

1.3.1.6 CEREAL STRAWS (Fig. 1.9)

Similar in structure to esparto, but generally the fibres are wider and more bent. The lumen varies in thickness and is slightly more prominent, due to the thinner and less opaque cell wall. Contains the following associated fibre structures:

- Epidermal cells.
- Parenchymal cells.
- Annular vessels.
- Tracheid-like cells (see Glossary for explanation).

There are more variations in the plant structure of cereal straws than in most plants, owing to different climatic conditions and growth rates. The cellulose content varies more than other plant fibres, and is about the same as the hemicellulose content, i.e. around 15-25%. Lignin content is ca 30-45%.

1.3.1.7 BAMBOO

These fibres are very similar to the "straws", but are generally easily recognizable by their characteristic oval-shaped parenchymal cells which often appear in clusters. The cellulose content is about 56-66%.

Fibers for paapermaking

Locations of papermaking fibers in plants

- Seed hairs - cotton, kapok, thistle
seed pods: cat's claw, etc.
- Bast fibers - flax (linen), hemp, jute, ramie, mulberry
stems: potato, sagebrush, vines, cattail stalks, eucalyptus branches
- Leaf fibers - esparto, abaca, banana. sisal, agave, yucca, pineapple (pina),
palms, cattail leaves, cornhusks, etc.
- Wood - may be discounted for hand papermaking due to large amounts of lignin,
the difficulty of fiber separation, and shortness of fibers.
- grasses - cereal straw, bamboo, bagasse (sugarcane), pampass grass, papyrus, etc.

Prebeating treatment varies with the plant material. Fibers which have been processed into cloth (cotton, linen, jute, ramie, hemp) will need no treatment, except for a good washing or boiling to cleanse, possibly with washing soda.

Some plant materilas need only treatment with mild alkali - washing soda - to separate their fibers: cattail leaves and stalks, cornhusks, cereal straws, pampass grass, and kapok.

Most plant fibers require boiling in lye for 2-5 hours, depending on their stiffness and resistance to breakdown. Some may require a second boiling. A separate treatment with bleach will also serve to break down the lignin.

Bamboo and sugarcane should be hammer-beaten, preferably while still green, into shreds before boiling.

Many plant materials are used in a dry or dead state, but some are better when used green. Plant fibers will produce different colored pulps and different papers, depending on the time of year, green or dry, manner of boiling, etc.

Agave, yucca, and pineapple leaves should be picked green and should be physically scraped or pounded to remove the leaf fibers from the pulpy leaves (decorticated), then washed, dried, and boiled in lye. They may be picked dry and chopped, soaked, and boiled, but the nature and success of the paper will be less.

Ropes, twine, and string made from sisal, hemp, jute, manila (abaca), cotton, linen, or other fibers (read labels) may all be cut up for papermaking. They are usually more successful when boiled in lye.

Scraps and cutoffs of rag art papers and rag matboard may be recycled for hand papermaking by cutting into 1" squares and soaking in warm water for 3-5 days, changing the water twice a day, then beating lightly. The papers are usually stronger and more successful if some new rag pulp, or linter pulp, is added to the recycled pulp. This short-fibered recycled pulp is also used as a filler or additive to rag pulps, from 1/6 to 1/4 volume, to increase even formation.

Hand Papermaking Methods

	Western	Japanese or 'Oriental'	'Ancient' or Chinese
Type of method	Straining	Lamination	Pouring or dipping
Countries	USA, Europe, Japan, Canada, India, etc.	Japan, Korea, Taiwan, China	China, Korea, Nepal, Bhutan Thailand
Fibers	Cotton & linen mainly; also abaca, sisal, jute, hemp, etc.	Kozo, mitsumata, gampi, and a few other long fibers.	Hemp, mulberry, various indigenous plants.
Beating	Hollander beater; a prolonged, hard beating of the fibers.	Gently hand beaten or light mechanical beating of Naginata.	Hand beating; stampers
Vat mixture	Water and fiber	Water, fiber, and a dispersion agent. A viscous solution.	Water and fiber
Vat additives	None for 'waterleaf' paper. Sizing, clay, or pigments.	Only the dispersion agent; Tororo-aoi or nori-utsugi.	None
Mould	Wooden frame with permanent screen of brass or copper wire or polyester; woven or 'laid.'	Wooden frame with removeable, flexible screen of bamboo splits tied together with silk thread.	Finely woven cloth stretched over a wooden frame.
Deckle	Removeable wooden 'picture frame' fits onto and over edge of mould to define size and shape of sheet. Low, sloped sides.	Hinged wooden frame holds bamboo screen in place. Deep sides can contain much pulp and water.	
Sheet-forming	A STRAINING process. A single dip into the vat is brought up level as the water begins to drain through the mould surface. Shaken front-to-back and side-to-side to misalign fibers. Knots or lumps in the stuff are caught in the sheet.	A LAMINATION process. Repeated charges are scooped from the vat and sloshed back and forth and side-to-side across the surface of the mould. Repeated dips add to the thickness of the sheet. Lumps or long strands in the stuff are kept in constant motion and do not form into the sheet.	A POURING process, sometimes a DIPPING process. Pulp is poured over the screen until an even layer is achieved. Hands may be gently used to achieve evenness. Dipping is similar to Western method.
Sheet transfer (Couching)	The mould is inverted and pressed in a flopping motion against a damp felt, transferring the sheet off the mould. A new felt or blanket is laid down before the next sheet is couched.	The hinged deckle is opened and the flexible screen (su) is removed. The inverted screen is rolled down and up against the stack of wet paper, transferring the new sheet. No felts separate the sheets.	None. Sheet remains on screen.
Pressing	Stack of sandwiched paper and felts (the 'post') is pressed quickly with a lot of pressure in a hydraulic or other mechanical press to remove water. Takes 15 to 60 minutes.	The finished stack is pressed slowly with a simple weight device, coming over a long period of time to a light or moderate pressure. Takes about one day.	
Parting the sheets	Sheets are delicate, but separate easily from the felts.	Separation of sheets from the stack is slow and difficult.	
Second pressing	Sheets are stacked on each other, making a feltless post for a second, lighter pressing.		
Drying	Single sheet or 'spur' drying over lines, on open screen shelves, or between blotters. One to 5 days. Sometimes force dried with photo print drier or such.	Damp sheets are brushed onto wooden boards for drying outdoors or force-dried by brushing them onto heated metal surfaces. A few hours to a few minutes.	Frames with pulp sheets are placed outdoors to dry. Then the sheets are peeled off and the screens reused.
Thickness	'Thick' papers. Western book weight or thicker.	'Thin' papers. Western book weight or thinner.	Thin or thick.
Sizing	May be 'internal' sized in the vat or 'tub sized' after drying by passing sheets through tray of gelatine or glue size and then pressing and drying again.	Generally unsized. Dispersion agent sort of acts as a size. Glue size may be brushed onto dry sheets.	
Coloring	From the colors of the rags or natural materials. Fibers may be bleached or dyed before beating. Pigments may be added to pulp.	Usually from the natural colors of materials; may be bleached. Fibers may be dyed before forming.	Natural. Sun or water bleaching.

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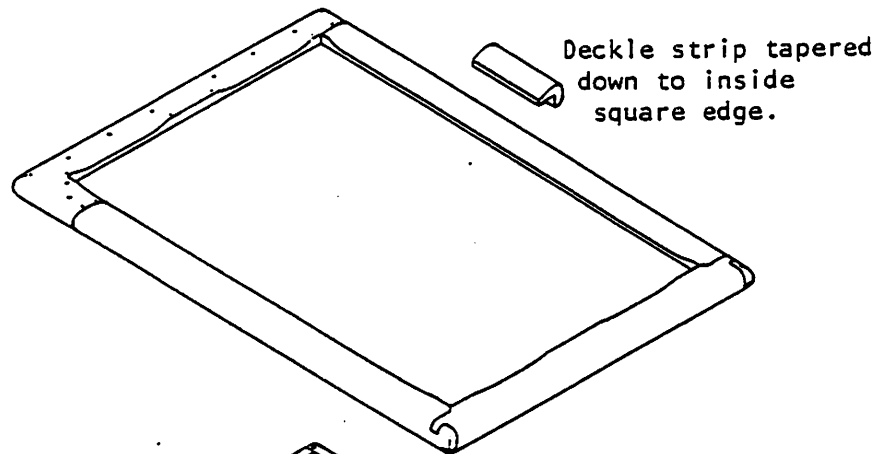
Basic Construction and Options

The deckle is constructed of straight-grained Honduras Mahogany with traditional joinery. The joints are fastened with waterproof glue and the deckle is waterproofed with a penetrating sealer. Each deckle is individually fitted to its mould or pair of moulds. Both ends of the deckle may be sheathed in brass to make the deckle more durable in production use.

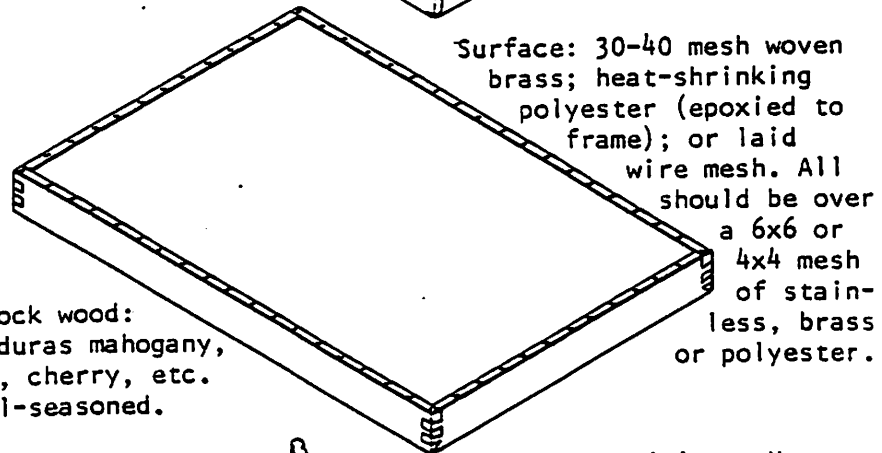
Optional diagonal bracing is available on larger moulds to prevent racking. Cast brass corners are also available. These strengthen the corners and reduce wear. These are screwed to the bottom edges of the mould along with maple rub strips. If rub strips are not desired, the brass corners may be mortised into the bottom of the mould and its bottom edges rounded to match. Standard moulds come with rounded bottom edges.

The frame of the mould is made of straight-grained Honduras Mahogany; ribs are White Pine. One or two bronze rods run at right angles to the ribs as reinforcement. All joints are fastened with waterproof glue and the entire assembly is waterproofed with a penetrating sealer.

Flat brass trim is also optional and is available as four separate corners or with a continuous front piece as pictured.



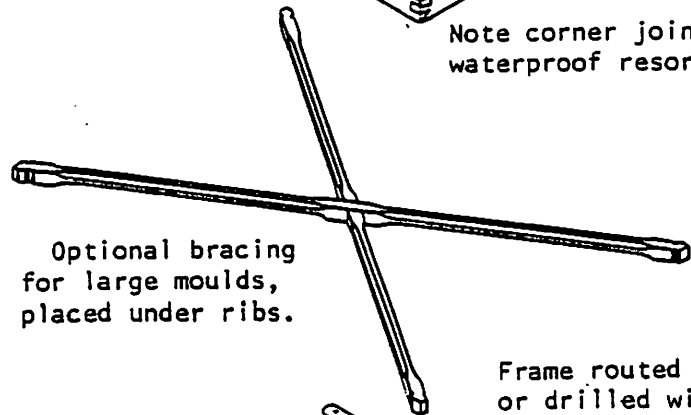
Deckle strip tapered down to inside square edge.



Surface: 30-40 mesh woven brass; heat-shrinking polyester (epoxied to frame); or laid wire mesh. All should be over a 6x6 or 4x4 mesh of stainless, brass or polyester.

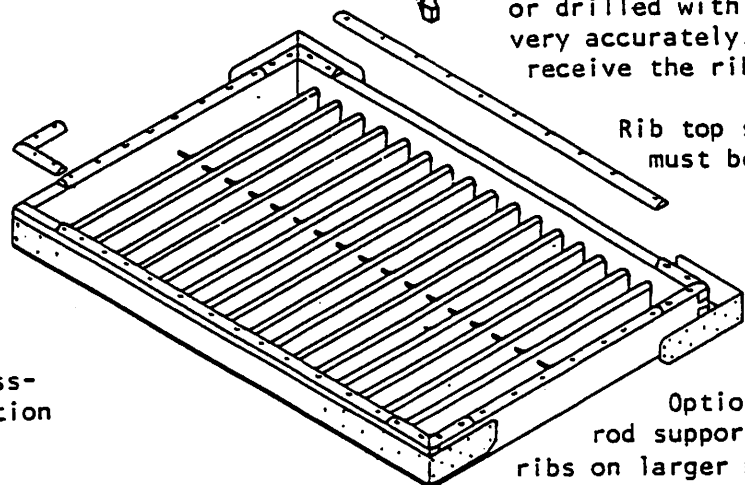
Stock wood: Honduras mahogany, oak, cherry, etc. well-seasoned.

Note corner joints. Use waterproof resorcinol glue.



Optional bracing for large moulds, placed under ribs.

Frame routed with slots or drilled with holes, very accurately, to receive the ribs.



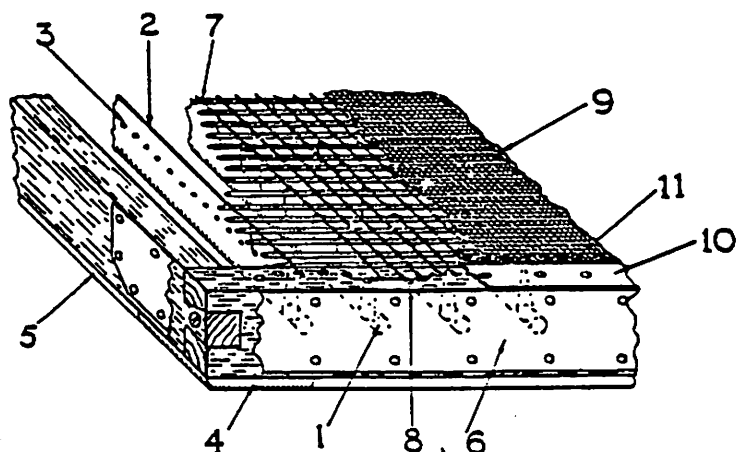
Rib top surface must be FLAT.

Optional brass rod support through ribs on larger moulds.



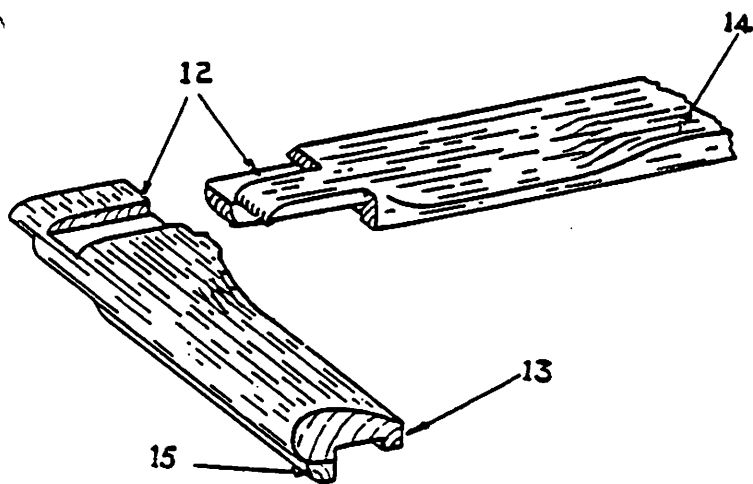
Rib cross-section

A complete and traditional mould from Paper Making by Hand in 1967 by J. Barcham Green



Details of a mould, showing the various wires and ribs

1. holes drilled in frame to receive ribs
2. tapered rib. Placed about 1 1/8" apart.
3. stitching holes drilled 5/16" below surface.
4. optional metal corners for rough use.
5. optional half-round for rough use.
6. 24 ga. brass strip for front edge wear.
7. backing sheet of 6-to-the-inch mesh, stitched to ribs with fine bronze wire.
8. copper tacks holding edge of backing sheet down. Backing sheet is 1/8" short of the edge of wood frame.
9. facing mesh; either woven wire or laid. Stitched to ribs with fine bronze wire. Mesh is 1/8" short of frame edge.
10. 3/8" wide copper strips tacked down over edge of mesh with copper tacks.
11. holes pushed in mesh with awl where mesh meets frame for better drainage.
12. deckle corner joint. Use waterproof resorcinol glue for all joints.
13. deckle is tapered down to a square inside edge; 3/16" high for normal paper, 3/8" for heavy sheets.
14. sides of deckle sanded for comfortable hand grip.
15. overhang strip for snug fit of deckle over mould. May also be cut as part of the deckle in one piece.



Details of corner of deckle, to retain the stuff when dipping

Note: Inside dimension of deckle defines sheet size. Mould frame must therefore be larger than projected sheet size. Inside edge of deckle should overlap the inside of the frame by about 1/2", covering the drainage holes.