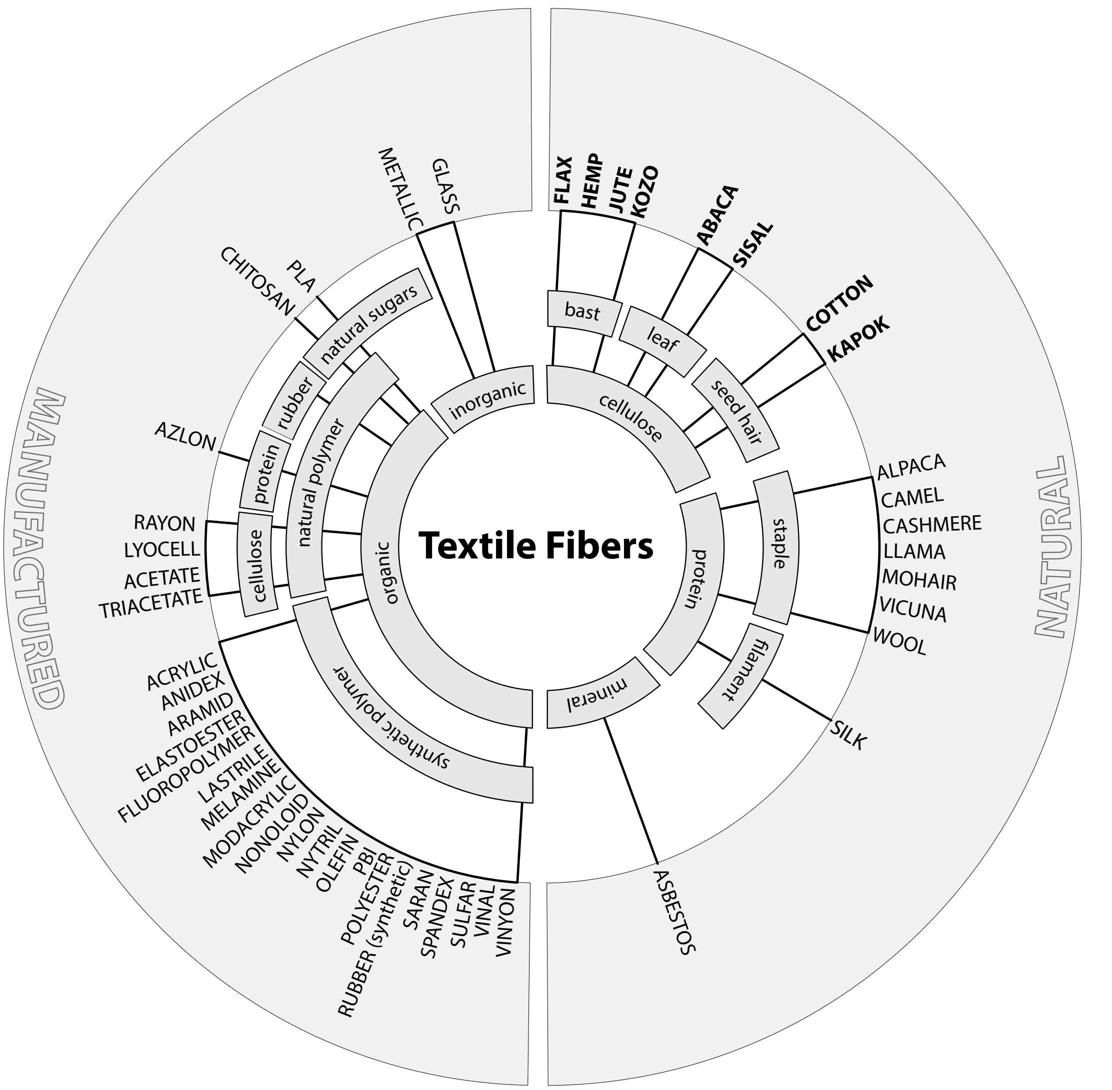
# Determinate Hand Papermaking

## I

## Introduction

Fiber, Freeness, Papermaking Suppliers

Acknowledgments





*Text and illustrations by*

Donald Farnsworth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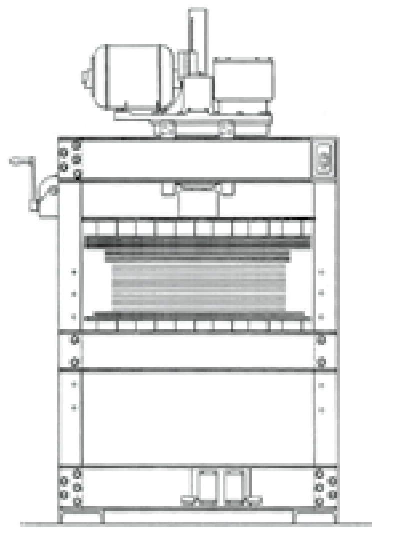
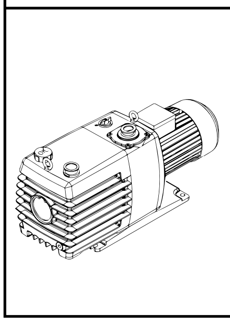
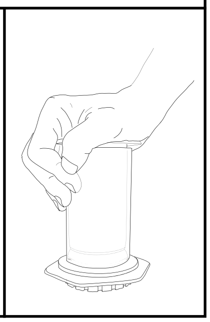
# Making a sheet of paper of predetermined content, weight, texture, & screen pattern







When making small sheet by hand one might wonder if sponging or a hand-operated coffee maker can provide enough pressure to press a newly formed sheet. Here are some comparisons:

**20-Ton Hydraulic Press**
20 tons = 40,000 pounds
22 x 30 inches = 660 square inches
40,000 ÷ 660 square inches = **60.6 psi**

**Vacuum table**
Many papermakers use a vacuum table to remove water and press paper. If it were possible to pull a perfect vacuum at sea level, their psi = 14.7 psi (or 29 in Hg [inches of mercury]). Using Magnolia's vacuum table we are able to achieve 23 in Hg = **11.3 psi**

**AeroPress:**
A 2.25 inch diameter circle = 3.97 sq. in.
90 pounds hand pressure ÷ 3.97 sq. in.
= **22.6 psi**

Making large-format sheets of paper by hand poses numerous difficulties, since tools such as moulds, vats, hydraulic press, and felts must all be scaled up accordingly. On the other hand, the production of high-quality sheets of small dimensions is a relatively simple undertaking. Working at a small scale, the determination of complex criteria such as content, weight, watermark, and texture of the finished sheet can be simplified as described in this series.

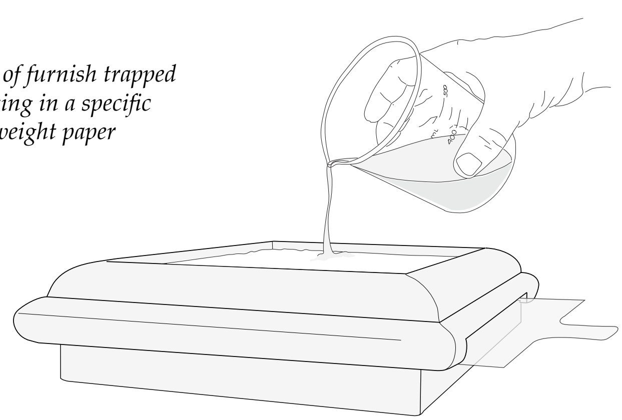
This series investigates:
No. I: Introduction: fibers, describing hydration, fibrillation & freeness.
No. II: Retting: lignin removal using mycilium.
No. III: Calculating paper weight with a smartphone app.
No. IV: Finding the surface area of an irregular sheet.
No. V: Blender processing paper fiber.
No. VI: Formulating pulp for color and content.
No. VII: Making paper with a 3D printed deckle box and an AeroPress.
No. VIII: Techniques for forming laid and wove paper without a vat.
No. IX: Drying handmade paper.
No. X: Sizing and burnishing.

These techniques may all be selectively applied, modified, or recombined to suit the individual or project at hand. The tools used include standard or easily available items like an Aerobie AeroPress coffee maker as well as custom 3-D printed wove and laid paper moulds. All described processes are capable of making highly refined and beautiful sheets of paper.

## Western papermaking

When forming a sheet of handmade paper using a traditional mould and deckle, one dips the mould into a vat of furnish (pulp with additives) with a scooping motion; some furnish spills off and the remaining stock drains, caught on the sieve-like surface of the paper mould, forming a sheet. As "white water" (the water that drains from the mould) drains back into the vat as pulp is removed, the vat concentration changes as the process repeats; this change in concentration results in papers of various weight, but not to exact specifications. In this series we will be using more of a redesigned "deckle box" approach, where we pour furnish into a confined space; all of the furnish we pour will become the sheet, allowing us to accurately predict the finished paper's characteristics.

*A known quantity of furnish trapped in the deckle resulting in a specific (knowable) GSM weight paper*



# Raw material - Western

In early Western papermaking, paper was made from linen and hemp rags that had been retted, often cooked in an alkali,[1] and flushed with water while being pounded to a pulp. This is a fine place to start, but a bit equipment- and labor-intensive. We can skip all that hard work by turning to paper pulp suppliers who sell various fibers that have been partially processed and are ready for blending or beating and sheet forming. Paper suppliers sell many varieties. Some need only be blended; others (like kozo) need to be cooked and pounded.

*1. The "cook"– i.e., rags and other fibrous material boiled in an alkali – serves to remove lignin, a class of complex organic polymers that fill the spaces in the cell wall between cellulose, hemicellulose, and pectin in plants. Flax has about 2% lignin whereas hardwood is comprised of approximately 29%, with lignin and softwood at 22%.*

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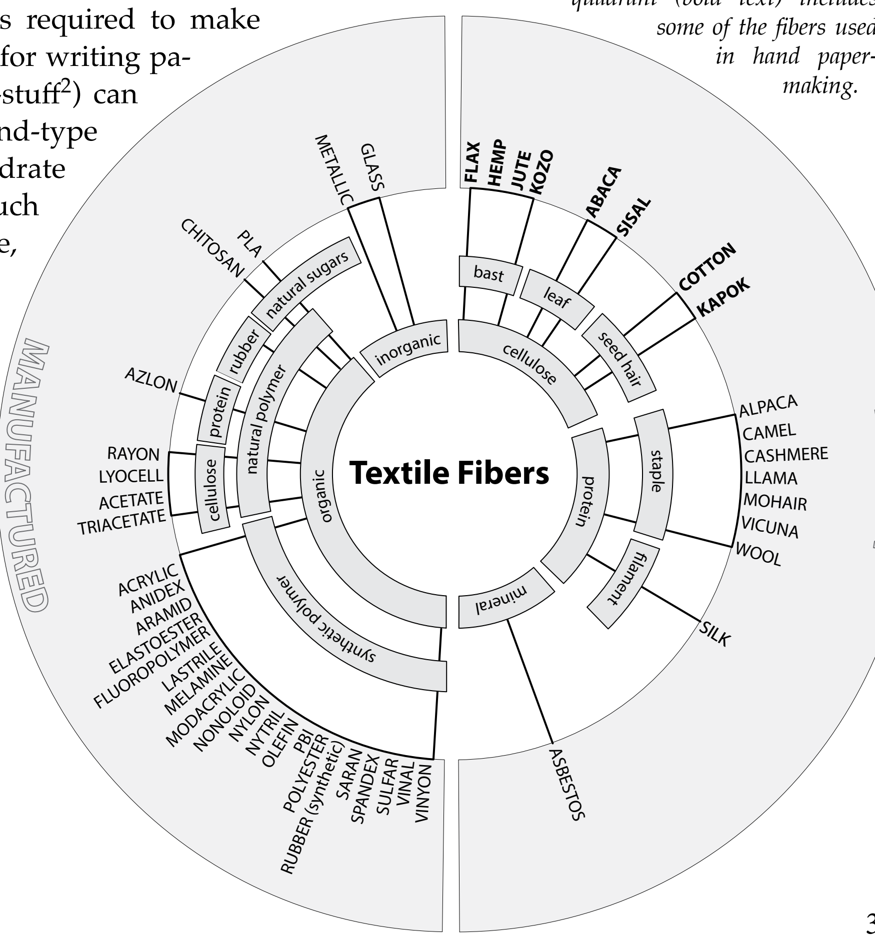
**Western papers**

Today the list of possible fiber choices is long and daunting; after all, every plant has cellulose fiber that can be made into paper one way or another. We will steer away from the hardwood and softwood so commonly used in commercial papers to focus here on archival (lignin-free) content papers. Besides the aforementioned linen and hemp, one can produce a wide variety of paper from flax roving, abaca half stuff, cotton rag, and cotton linter. Each has its own appeal, characteristics, and processing needs.

*2. "Wet-lap" or "half-stuff" is available as sheets, rolls, or bales, all generally dry; the name wet-lap comes from the Fourdrinier process of manufacture. Typically more refinement is necessary to make various grades of papers. Half-stuff is well named as it describes pulp (sometimes called stuff) that is only half-processed.*

Whereas linen is more likely to make crisp, rattly writing paper with very little processing, fibers sourced from seed hair (like cotton rag and linter, for example) can produce blotter paper when beaten briefly; further processing is required to make printmaking papers and even more for writing papers. Cotton staple fibers (rag half-stuff[2]) can be robust and strong when a Holland-type beating engine is used to defiber, hydrate and fibrillate the rags. To make such a paper more dimensionally stable, retted and lightly beaten linen can be added; this is more or less the formula used to make the art papers popularized by J Whatman, England's papermakers for the Arts and Crafts Movement. Cotton linter, the fuzz found closest to the seed, is commonly used as a filler fiber to provide bulk, combined with stronger, longer fibers.

*Textile Fibers chart: although all fibers can be added to paper for decorative, fire retarding and anti-forgery purposes, the upper right quadrant (bold text) includes some of the fibers used in hand papermaking.*



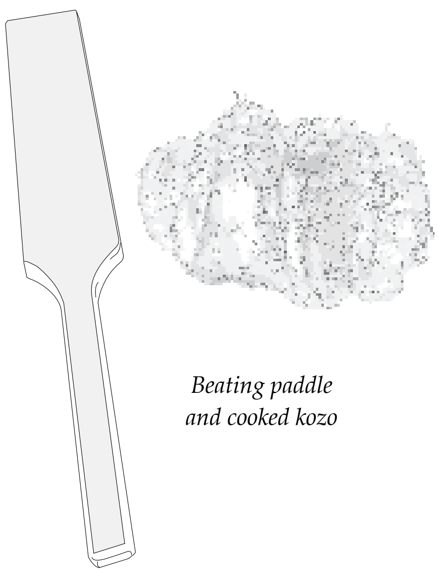
# Raw material - Japanese

3. Bast fiber is the fibrous material from the phloem (living tissue of a plant) — the inner bark "skin" fibers that surround the stem. Bast fibers are soft with nodes for flexibility. Cotton contains little hemicellulose and no nodes.

Obtained from the phloem or outer bark of jute, kenaf, flax and hemp plants, bast fibers[3] (similar to traditional Japanese paper fibers) are very durable due to hemicellulose, a natural binder not found in abundance in seed hair fibers. Treated properly, these bast fibers can produce a crisp, rattly sheet of paper without a prolonged process of brutally beating and hammering on the bark fibers.

**Japanese paper fibers**

Kozo, mitsumata and gampi are the three main fiber species whose inner bark (bast) fibers are used in Japanese papermaking. Hemp, mulberry, bamboo and straw are used to make washi. If you elect to use these amazing plants, the inner bark (with the outer bark already stripped) is also available from papermaking suppliers. Preparing these fibers for papermaking requires soaking, cooking for half a day in a mild alkali (like soda ash), rinsing, and pounding with a mallet. In this papermaking paradigm, longer processing (cooking) produces softer paper while shorter cooking yields harder paper, as more of the natural binder hemicellulose is lost the longer it is left in the cook.



*Beating paddle and cooked kozo*

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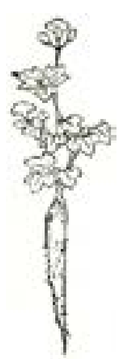
## Additives:

***Japanese and Western paper:***

Calcium carbonate (raises the pH, and acts as a buffering agent to improve longevity); magnesium carbonate (an anti-oxidant), titanium dioxide (a whitening pigment); clay (for a smoother and more opaque paper); methyl cellulose (a mild paste); colorants and inclusions can be added to both Eastern and Western paper.

***Japanese:***

Tororo-aoi is used to make neri, a starchy substance crucial to the manufacture of making washi. This slimy additive is blended with the pulp to make a more even sheet. Tororo-aoi (neri) is derived from the *Abelmoschus manihot* root, a flowering plant in the mallow family Malvaceae; it acts as a formation aid, but does not size the paper. Tororo-aoi is always used in Japanese papermaking, but can also be added sparingly to Western bast fibers like flax and abaca.



*Tororo-aoi*

# Fibrillation, hydration, freeness & hemicellulose

**Overview:** ***Fibrillation*** *and* ***hydration*** *are the results of pulp processing in a beating engine; pulp's* ***freeness*** *indicates the effectiveness of this processing, measured by how freely the pulp surrenders its water.* ***Hemicellulose*** *in the raw material imparts similar characteristics without processing.*

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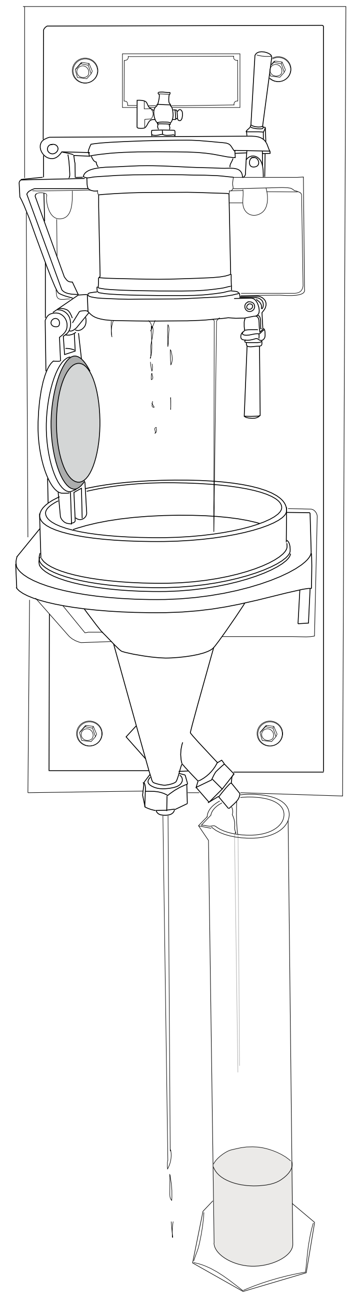
**Fibrillation** is the fraying of a raw material's cellulose fibers during processing. Increased fibrillation results in more bonding potential between the fibers, making a stronger, harder, and eventually a more translucent paper: highly fibrillated pulp makes a sheet with fewer interstices, allowing light to pass through the translucent cellulose fibers. As water is removed during sheet formation, pressing, and drying, the pulp's fibers "zipper" together due to hydrogen bonding between hydroxyl groups (oxygen and hydrogen atoms) in the cellulose and hemicellulose. The electrostatic interaction of polar water molecules with hydroxyl groups of contiguous fibers is the key to understanding why paper is paper and not just tangled fibers (i.e., felt).[4]

*Canadian Standard Freeness tester*



**Freeness** is measured as the speed at which a pulp drains, which tells us its degree of hydration and refinement due to beating or processing. Using a Canadian Standard Freeness tester (CSF) we can measure freeness to determine the effectiveness of the refining process, i.e., the swelling of the pulp fibers as a result of beating. A freer pulp drains faster on the mould; more refinement causes more swelling, yielding a slower draining pulp.

**Hydration,** linked to fibrillations, is the swelling with water of the tubular cellulose fibers caused by the constant pounding in the beating and processing stage; this not only makes slow draining pulp, but causes shrinking during drying.

The **hemicellulose** content of a given fiber type plays a critical role in determining the behavior of a pulp or sheet made from that fiber. Hemicellulose is embedded in the cell walls of plants and consists of polysaccharides, like cellulose, but arranged in shorter, branched chains. The hydroxyl groups in hemicellulose contribute to the strength and continuity of the paper's fiber network, creating a stronger, crisper sheet without additional beating. Tear and tensile indices are directly proportional to the cellulose/hemicellulose ratio. Cotton, a seed hair fiber, lacks the critical bonding capacity of the hemicellulose found in bast fibers such as linen and flax or paper mulberry fibers used in Japanese papermaking.

*4. For a detailed explanation of this process, see "Contribution of Hydrogen Bonds to Paper Strength Properties" by Przybysz et al:* ***http://journals.plos.org/plosone/article?id=10.1371/journal.pone.0155809***

## Papermaking Suppliers

***Supplies & fiber*:** Carriage House Paper, Brooklyn NY
www.carriagehousepaper.com

***Supplies & fiber*:** Twinrocker, Indiana
www.twinrockerhandmadepaper.com

***Evolon (polyester/polyamide microfiber material):*** Atlantic Papers, Ivyland, PA
www.atlanticpapers.com

***Churro felt:*** Lana Dura
www.lanadura.com

***Small mould, pressing block, burnishers:*** Miguel Mendoza/M Squared Fine Woodworking, Oakland, CA
Miguel.msquared@gmail.com, (510) 832-2822

***Breather Mesh:*** http://veneersupplies.com

## Series links:

No. I: Introduction: fibers, hydration, fibrillation & freeness and suppliers
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