Paper Fibers and Books

By Werner Rebsamen – "So many books and so little time" is a well-known slogan this writer has seen posted on t-shirts. For all who love books, it is a dearly treasured topic, and yes, many of us collect favorite books as well. When the origin of books is studied, at least in the Western world, it always seems to start with scrolls of papyrus or, later-on, actual book blocks made from parchment. This is a chapter for itself and one with which our readers are most likely very familiar. Let's not talk about the many kinds of items we call books, like tablets, scrolls and even the latest, notebook computers. Let's discuss the kinds of fibers used to make today's papers for books, how they react and perform, and how they age.

Who invented papers like the ones used today?

This honor belongs to the Chinese. Around 105 A.D., Tsai Lun used rags and plant-fibers like hemp or china grass and bark. With these ingredients, Lun managed to produce the very first kind of papers. Crushing these items created long fibers and soaking them in lots of water resulted in pulp. A fine woven bamboo mat served as a screen. Pressing the pulp and drying it created the very first actual paper. (Today's "Kozo" handmade Japanese papers, made from the inner bark of mulberry trees, are very similar to those earlier papers.) Other materials like bamboo fibers were used in the 12th century; rice straw was used in the 13th to 15th century. For approximately 500 to 600 years, the Chinese maintained the paper making process as their secret. Via caravan routes through northern Africa, the skills of papermaking then found its way to Europe. On the web, look up the December 29, 2006, *New York Times* story "The Story of Islam's Gift of Paper to the West."

A general rule when planning for printing and binding a book is to have all cellulose materials, including the text block, endpapers cover board, and covering materials parallel to the spine.

As many are aware, the very first paper-like materials, suitable for writing, were made by the Egyptians approximately 5,000 years ago. Many are familiar with papyrus, a plant which grows along the Nile River. Although paper may have gotten its name from papyrus, it is not paper as we know it. Why? The fibers of the papyrus plant were not separated as they are in modern papermaking.

When were the first industrial papers made?

Papermaking entered Europe via Northern Africa in the 13th century. The Arabs introduced linen fibers from the flax plant to supplement hemp fibers. While such papers were suitable for calligraphy and oriental writings, they were unsuitable for the strong impressions used in combination with Gutenberg's moveable type. Europeans then started to make harder papers, using gelatin-sized cotton and linen fibers. In the 19th century, new techniques had to be developed to meet increased demands for papers. Under the slogan "save our rags", they experimented with straw pulp, wood and esparto grass. Wood, as a fiber source, was already suggested by a French scientist as early as 1719. He observed wasps making "paper" from wood. But it took another 150 years until industrial production using wood pulp started. Credit for this technology belongs to Charles Fenerty, a Canadian youth, who began experiments with a "chafing" machine and, in 1844, succeeded in making a sheet of paper from wood. The same year, Gottlob Keller of Germany, patented the very first, practical wood-grinding machine, launching a new area in papermaking.

North America's first commercial ground-wood mill was started in 1866 at the Butin mill, in Valleyfield, Quebec. A year later, this was followed by a mill in Massachusetts. In other parts of the world, it was discovered that bagasse fibers obtained from crushed sugar cane stalks could also be used for papermaking.

The process of cooking wood chips in caustic soda, and the use of sulphite and acid had its consequences. Preservation librarians are all too familiar with this issue.

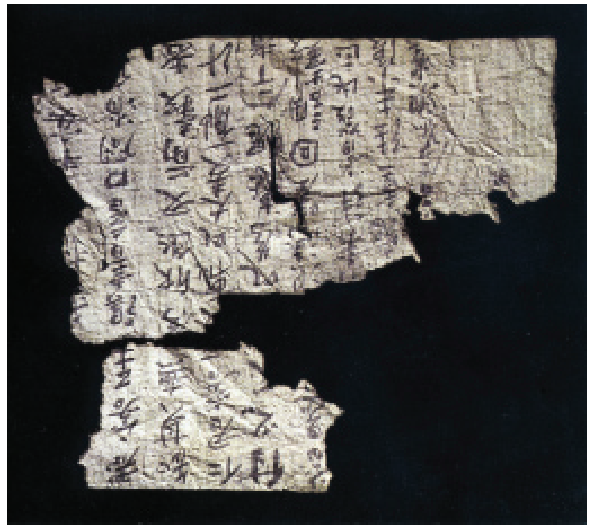
What kind of fibers are in today's papers?

Good question. It is a shocking fact, that according to paper experts, non-wood fibers account for about 7% of the world's papermaking fibers. In North America, non-wood fibers represent less than 2% of its fiber consumption. Yes, rags still make the best kinds of papers. A few years ago, during an LBI meeting in Montreal, we visited a unique papermaking plant. Old, worn-out jeans were used to make a high quality pulp. In North America, non-wood fibers are used for papers which must meet specific purposes for which wood fibers are unsuitable. Cotton-derived fibers, like the jeans, are used for high-grade, permanent and durable papers like currency, ledgers, and writing papers. Bible and other lightweight printing papers are manufactured with linen fibers. There are, of course, many other fibers used for specific papermaking purposes. Jute fibers, from burlap cuttings, make hard, durable Bristol, tag and cover papers. In a lecture at RIT, a well-known paper expert, Mr. Leonard Schlosser of Lindenmeyer Paper, once demonstrated to our students that the industry can make paper virtually out of anything that contains fibers.

Selecting the right fibers for a particular kind of paper is a science. There are 35,000 kinds of wood and more than 1,000 of these grow in North America. But only about 100 have any commercial value and must be divided into "soft-wood" (40%) and the balance into hard-wood. Papermakers are only concerned with the cellulose and lignin parts. The cellulose portion is what becomes paper. These fibers are composed of individual fibers which are finer than human hairs and measure their length in millimeters. The lignin is a chemically complex substance which binds the cellulose fibers together or, in other words, it is the "glue" that binds the fibers together. Hardwood fibers are short; softwood fibers are generally longer.

How are fibers imbedded into paper?

The actual papermaking process is complex and space does not allow it to be described in detail. Basically, there are four main types of pulp:



Historic documents are hand-made papers; the fibers are long and distributed evenly in all directions.

- Chemical Wood Pulp which is made by pressure-cooking wood chips with chemicals separating the resins and lignin from the cellulose. Because there is little lignin left, yellowing does not take place.
- Mechanical Wood Pulp known as ground-wood. Low cost, high yield used in newspapers. Pulp contains high amounts of lignin. Now you know why your inexpensive paperbacks and newspapers turn yellow in no time.
- Old Paper Pulp (recycled) which is made from old newspapers, office waste, and magazines.
- Rag Pulp which, as stated earlier, is made from rags (cotton, for example). Pulp makes a high quality strong paper.

To manufacture papers, there are several steps required – cooking, chemical recovery, cleaning, bleaching, refining, and then the various processes on the papermaking machine itself. For those involved in preservation, it may be important to know that there are two different kinds of bleaching processes. One is without using chlorine called TCF. However this process is less than 3% of the world's paper production. The ECF process uses chlorine dioxide but no chlorine. Although they have similar names, they are different chemicals. Most white papers are now made using the ECF process.

The type of refining process used, then, results in the kind of fibers in a particular paper. A fiber is smooth like a garden hose. After refining the fibers, tiny “hair-like” strands are exposed on their sides. In the papermaking process, the fibers float along with the water, but those “hairs,” perpendicular to the length of the fiber, start to bond them together.

There are different concepts of papermaking machines which determine the distribution and alignment of the fibers. On the Fourdrinier system, more fibers are on the bottom or the wire side. In the Twin or Top Former process, the fibers are more equally distributed, however, they all are more or less aligned in the direction of the web.

What kinds of papers are used for books?

There are many different finishes and paper grades. Generally, they are separated as uncoated or coated, dull or glossy. Typical materials used to enhance papers are starches (corn or potato, for example) or wash coatings which use clay or latex. A calendar can give a coated paper a smooth or glossy finish. The basic paper make-up consists of the following:

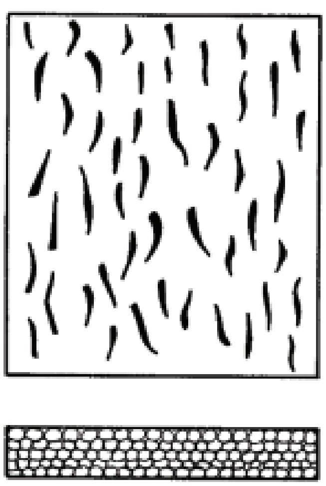
- Fiber which is the basic raw material for paper (cellulose)
- Internal sizing is used to resist feathering from ink pens. Materials used are alkaline sizing (AKD) and rosin (Acid sizing) ASA.
- Fillers are the material added to or mixed with the fiber to give brightness and opacity. These materials are usually pigments such as calcium carbonate (alkaline papers) titanium dioxide, or clay (acid papers).
- Surface Starch is used to seal and protect the surface of the paper for printing. Surface starch is used to prevent fiber and other materials from releasing and contaminating the printing systems.
- Dyes are used to color the paper. Several dyes can be used to make various shades of white or deep colors.

One item of importance for bookbinders is the lack of fibers in today’s coated papers. Fibers are the expensive parts. In earlier times, just a decade or two ago, coated paper had 20 percent of filling materials added. Now, the average is approximately 35 percent. One of my colleagues at FOGRA, Germany’s leading paper and ink research institute, informed me that they evaluated some coated papers which contained 54 percent of filling materials! When adhesive binding, exposed fibers are relied upon to bond a binding together. Clay-coatings are anything but ideal to achieve a strong bond.

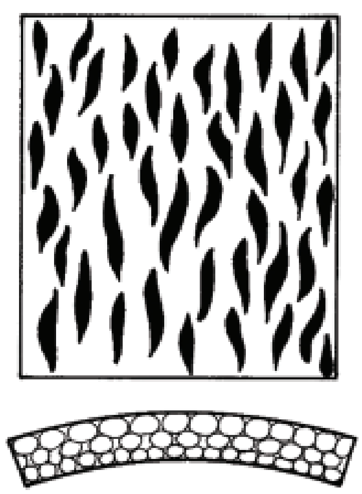
When discussing paper, the industry must consider other aspects like basic weight, brightness, bulk, caliper, density, dimensional stability, felt side, folding endurance, formation, ink absorption, ink holdout, ink mottle, opacity, porosity, and wire side. For bookbinders, the following paper properties are likely the most important:

- Free Sheet is paper which contains little or no mechanical wood pulp (ground wood).
- Acid Free Paper is paper manufactured to a neutral or higher pH reading. For example, 7.5 pH. Paper also known as alkaline paper.
- Acid Paper is paper manufactured under acidic conditions which is normally made with alum and Rosin, pH ranges 5.0 – 6.5.

On machine-made paper, the grain direction runs parallel to the web of the paper making machine. Moisture will expand the fibers 4 to 5 times more in their width than in their length. Add a little water to one side of the sheet and compare.



Dry sheet



Moisture applied to sheet

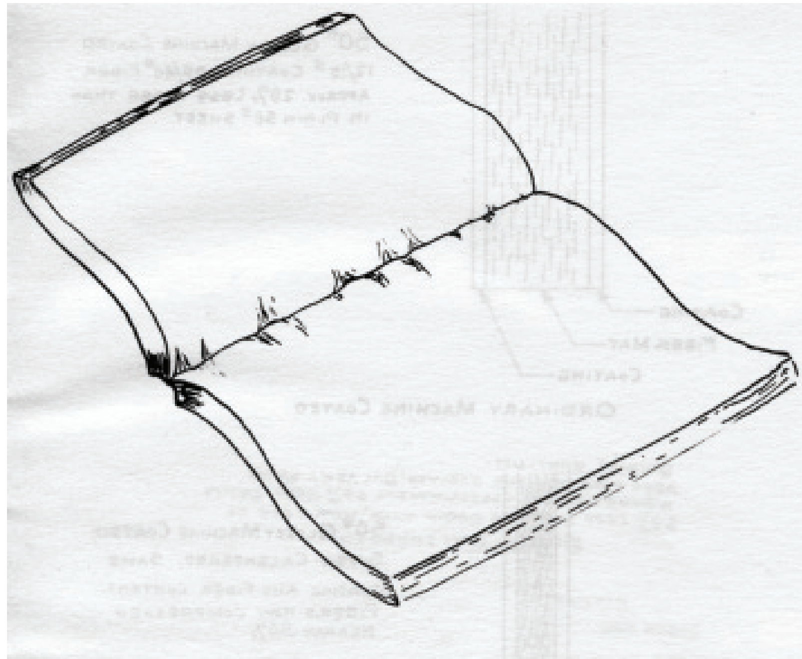
Paper grain direction

As stated, fibers travel and align themselves in the direction of the paper web. It is estimated that more than 3/4 of all the fibers align themselves in this direction. This is called MD, machine direction. CD is the cross direction. The grain itself is a most important factor for printing and binding. The grain direction affects paper in both folding and tearing. Paper will fold smoothly with the grain direction and roughens or cracks with folding against the grain. Paper will expand or contract more in the cross direction when exposed to moisture changes. Paper should always have the grain parallel with the binding edge. Then the sheets will turn easier and lie flat when turned.

Environmental conditions change virtually every day. On a rainy day, humidity increases. During cold winter days, the moisture in the air is much lower. All cellulose fibers need to adjust. What happens if environmental conditions change? The fibers will expand in their width four to five times more than in their length! Imagine a book printed with the grain direction perpendicular to the binding edge as most low-cost, newsprint like paperbacks are done. The sheets are locked into the spine with an adhesive. The paper fibers want to expand but cannot do so in the spine. The results are waves or very noticeable distortion. Can you imagine a book put together with different papers and grain directions? I have analyzed many such books and clients wondered why some pages were wavy or the adhesive binding split. Uneven stress exerted onto the relatively fragile binding was usually the cause. Therefore, a general rule when planning for printing and binding a book is, to have all cellulose materials, including the text block, endpapers cover board, and covering materials parallel to the spine. Problem is, many printing processes and resulting trim sizes or formats of books do not always cooperate and this is one of the major causes of physical problems with bound books.

Moisture Content of Paper

Finally, some may wonder why digitally printed text blocks - which most of the time have the grain direction parallel to the binding edge - show distinct waviness in the text block? This is a good question and many new digital printers scratch their heads



Paper fibers aligned perpendicular to the binding edge are unable to adjust to ever changing environmental conditions. On rainy days and high humidity, distortion becomes evident.

and wonder what is going on. Not only do the text blocks feature distorted paper, often the covers warp as well.

Paper is composed of millions of hollow, straw-like, cellulose fibers which respond to every slight change in atmospheric conditions. They expand when absorbing moisture and contract when giving off moisture. Paper has a moisture content of approximately 5 percent and is most stable in a relative humidity of 40 to 50 percent. Wavy edges or distortions within a text block are caused by the fact that the moisture in the air is greater than the moisture content of the paper. Consider digital printing. In order to create conductivity with the toner, the very first prerequisite of this printing process is to take all the moisture out of the paper. Notice the (hot) paper coming out of the copy machine. It is bone dry, full of static. It will take at least 72 hours until moisture will have a chance to be back in the paper. Waviness still present after such a time period is said to be permanent.

Conclusions

In this article, only a fraction about the manufacture of paper was covered. As stated earlier, paper and paperboard making is a science in and of itself and some universities offer Ph.D's in this discipline. This writer has had the pleasure of working together on many occasions with such scholars, solving industry problems with paper and various tasks of bookbinding. As the industry moves "forward" finding less expensive ways for the manufacture of paper and options for on-demand printing, these problems are on the increase. For example, fewer fibers in a coated sheet that is covered with four or more layers of toners represents problematic tasks for binding. The NISO standard for library binding specifies the "double-fan" process. This means that library binders apply the adhesive onto the sides of a sheet - a big difference if compared to conventional perfect binding.

Together with trade suppliers, such problems will continue to be addressed to the benefit of all who love books. Creating a well-bound, fine book that is aesthetically pleasing in every regard is always a most worthwhile goal.

Sources: Collected RIT lecture notes from various magazine, trade articles and Industry seminar notes. A special thanks to Jim Kohler, Senior Scientist, Graphic Arts Technology International Paper.

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