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Wood and How It Relates to the Paper Products

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WOOD AND HOW IT RELATES TO THE PAPER PRODUCTS

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ABSTRACT

Wood quality does influence the performance of paper and there are other "quality" issues to consider besides cost. The most obvious issue, and the one under reasonable control in most mills, is the ratio of hardwood to softwood pulp used in the paper or paperboard products. Wood species, wood age, and wood density control the shape of the fibers, their performance in the paper product, and ultimately, influence customer satisfaction with the product. This paper will review some of the contributions wood makes to paper performance and performance problems, and will attempt to highlight some of the issues in trying to satisfy the mill accountants, pulp mill manager, paper mill manager, converting operations, and the end user — all at the same time.

Keywords: Fiber morphology, mechanical pulp, coated paper, paperboard, linerboard, spruce, western hemlock, douglas fir, southern pine.

INTRODUCTION

In an effort to review the needs of the paper industry for wood fiber form, this paper will consider the product requirements of various paper and paperboard grades and attempt to identify fiber characteristics that contribute to a superior product. For softwoods, the following genera will be considered: spruce (white, black, and norway), western hemlock, Douglas fir, and southern pine (loblolly and shortleaf). Among hardwoods, the oaks (white and red), sweetgum, birch (paper), and aspen will be reviewed. Table I summarizes average wood density and typical fiber characteristics for these genera.[1,2,3]

The papermaker has three major pulp groups to use in paper — chemical softwood pulp, chemical hardwood pulp, and mechanical pulps. The choice of furnish mix is based on cost and performance. Softwood kraft pulps generally give higher tensile and tear strength and are used to enhance strength where this is critical. Hardwood kraft generally improves formation. The sheet compression strength of hardwoods approaches that of softwoods, but tear and tensile strength are measurably lower (Table II)[2,3,4]. In most of the United States, hardwood kraft pulps can be produced at lower cost than softwood kraft pulps and this provides an incentive to incorporate hardwoods to the maximum extent products will allow. Mechanical pulps are

Table I. Fiber characteristics of common U.S pulpwoods.

Species	Specific Gravity	Fiber Dimensions: Length mm	Diameter μm	Wall μm
Loblolly	0.47	3.5-4.5	35-45	4-11
D. Fir	0.43	3.5-4.5	35-45	3-8
W. Hemlock	0.38	2.5-4.2	30-40	2-5
W. Spruce	0.37	2.5-4.2	25-35	2-3
White Oak	0.59	1.4	14-22	5
Sweetgum	0.44	1.7	20-40	8
Birch	0.48	0.8-2.7	20-36	2-3
Aspen	0.35	0.4-1.9	10-27	2-3

Table II. Typical paper physical properties for softwood and hardwood kraft pulps.

	Coarseness μg/m	Tensile Index, N·m/g	Maximum Tear Index mN·m/g
Spruce	140	135	20
W. Hem.	220	120	18
D. Fir	264	90	30
S. Pine	280	85	28
Oak	143	67	11
Gum	266	96	13
Birch	116	101	9
Aspen	122	103	8

considerably lower in strength than either softwood or hardwood kraft pulps (Table III), but offer good opacity and bulk.

MECHANICAL PULPS

The kraft pulping process is highly tolerant of wood species. In mechanical pulping however, fiber characteristics are a dominant variable and exercise considerable control over the paper quality. Typical quality data for mechanical pulps from the four softwood genera are presented in Table III.[5,6] The thin cell walls of spruce give the strongest and brightest mechanical pulp of the four and is generally the preferred genus for high-yield pulping. Douglas fir, giving low strength and low brightness is rarely used in mechanical pulping.[6]

Table III. Typical energy requirements and properties of softwood TMP.

	Genus			
	Spruce	W.Hem.	S.Pine	D. Fir
Energy kWh/BDT	1900	1960	2500	2750
Freeness, ml	120	80	100	100
Tensile Index, N·m/g	4.8	3.7	3.3	3.4
Tear Index, $mN \cdot m^2/g$	9.7	8.3	7.3	6.3
Brightness	59	56	58	53

Traditionally, wood density has been the parameter most associated with differences in high-yield pulp quality between species. However, wood density cannot directly control mechanical pulp quality. Some aspect of fiber structure that correlates well with wood density must be the controlling factor. Recently, Karnis has emphasized the role of fiber coarseness in determining strength development and energy requirements in mechanical pulping.[7] Fiber coarseness, measured as μg/m, is a measure of fiber wall mass per unit length of fiber and is the equivalent of denier in synthetic fibers. In synthetic fibers which are solid and nominally circular in cross section, mass per unit length is a useful measurement. The fibers' diameter, flexibility, and surface area are all correlated. In wood fibers, mass per unit length is not a singularly useful measurement. As an exaggerated example, a fiber with a 25 μm diameter and 4 μm wall thickness has nearly the same coarseness as a fiber with a 45 μm diameter and 2 μm wall thickness but the performance characteristics of the two are quite different. The larger fiber has twice the surface area, is much more flexible, and will collapse on drying. Since paper strength in mechanical pulps has a significant contribution from fiber surface area,[8] a measure of fiber surface relative to mass is a critical aspect of species performance.[9]

COATED PRINTING PAPERS

The key requirements of coated printing papers include high tear strength, smoothness, low porosity, high paper surface strength, and high opacity. In groundwood or TMP content lightweight coated papers, the bulk of the tear strength is achieved by adding kraft softwood fibers and the opacity comes from the mechanical pulp and coating. In coated free sheet, hardwood pulps are used to help fill the sheet and the coating is adjusted to make up for the lost opacity. To obtain high gloss and even print density on coated paper, the final surface must be very smooth and uniform[10]. The coating on a sheet of paper is about 5μm thick[11], comparable to the double wall thickness of the average spruce fiber but just half the double wall thickness of a loblolly pine fiber. The coating process fills in the surface roughness of the sheet with a clay slurry, but the shrinkage on drying reproduces the original surface topography in reduced scale. Smoothness is also gained by calendering the paper but it can cause ink to absorb at different rates and reduce sheet strength and opacity; and once wetted in printing, fibers return to their pre-calendered condition.[11] In paper printed using the offset process, the smoothness gained in the calendars is largely lost.

To obtain both high smoothness and low porosity in the base paper, papermakers prefer low coarseness fibers with thin cell walls that collapse on drying and a high hardwood or mechanical pulp content to fill in the voids in the sheet.[11,12,13] Collapsed fibers conform to the surface of the other fibers in the sheet. This increases paper density, decreases porosity and assures that the maximum surface defect is on the order of one double wall thickness. Fibers with thick cell walls resist collapse and are unable to conform to the other fibers in the paper. This opens up the paper structure and increases porosity.[13] A larger fraction of the coating material is required to fill in voids in the sheet structure and less is left to cover the surface of the sheet. This results in a rougher final surface and more fibers protruding above the coating.

Surface Strength

The heatset web offset printing process is a torture test for coated papers. Starting with the low porosity base paper, the coating reduces the porosity even further. In the offset printing process, water is used to protect the non-image part of the printing blanket so the paper picks up moisture in the press. After printing, the paper is dried rapidly in an oven to set the inks. The water in the paper turns to steam which is restricted from expanding and escaping by the low porosity of the paper and the coating. The result is an internal force working to blow the sheet apart.

In lightweight coated papers containing mechanical pulps, the steam contributes to the phenomenon of fiber rise, reforming the lumens in previously collapsed fibers. In coated freesheet, the weak link is generally the interface between the paper and the coating leading to coating blisters much like a paint blister. Improved surface strength reduces the severity of both fiber rise and heatset printing blisters[14]. Good paper surface strength is favored by a high bonded surface between fibers. Bonded surface can be increased by mechanically tearing fibrils from the surface of the fibers or using thin-walled fibers with a large surface area to mass. In studies of fibers readily pulled from the surface of papers containing mechanical pulp, heavy-walled latewood fibers with a low surface area to fiber mass dominate.[15] As with smoothness and porosity, species with thin fiber wall such as the spruces and the true firs are preferred.

Manufacturers of lightweight coated printing papers prefer the lower density softwoods, primarily the spruces and true firs. Over 70% of the coated papers manufactured in the United States are produced in the northeast and north central states where white and black spruce and balsam fir are available (Table 4).[16] Producers in the southern United States can get some improvement by using wood sources with a high juvenile wood content (tops and thinnings), refining to lower freeness; and one southern LWC mill grinds cottonwood along with pine. Unfortunately, all of these methods sacrifice tear strength which is needed to run on the coater. In coated free sheet, improvements are possible by using juvenile wood sources and replacing high coarseness hardwoods like the oaks and sweetgum with lower coarseness hardwoods like cottonwood.

Table IV. Regional paper production by grade.

	Regional % of U.S. Production		
	South	N.E./N.C	West
Total Paper	53%	31%	14%
Newsprint	58	11	31
Coated Paper	22	71	4
Uncoated Freesheet	40	45	12
Bleached Board	89	0	11
Kraft Board	82	0	17
Market Pulp	67	16	16

UNCOATED FREESHEET

Uncoated freesheet is the general group of business paper grades, including forms bond, xerox copy, and printing papers. Some requirements vary by use, but all require high brightness and high opacity. Hardwood pulp content is usually high, between 50% and 80%. Most sheets contain 10 to 20% mineral filler, either calcium carbonate or clay. The major strength requirement is sufficient wet and dry strength for the paper machine. Quality problems tend to be grade specific but a major wood furnish related factor is vessel element pick in the offset printing grades.[17] This problem is most severe in areas with a large amount of oak in the hardwood supply but is also a problem with some tropical hardwoods.[18] Oak springwood vessels elements have diameters of 300 μm and a length of only 0.5 mm. They collapse in the sheet to form a nearly square 0.5 mm particle. This large flat surface forms weak bonds with the sheet and offers a large surface to printing inks. In offset printing, the ink tends to lift the vessel elements off the sheet. The vessel elements then accumulate on the press and reduce print quality.[17] In locations where oak is common, mills producing offset grades often limit the amount of oak in the hardwood furnish.

BLEACHED PAPERBOARD

Bleached paperboard is used in folded cartons and liquid packaging applications. Paperboard often contains a large amount of hardwood, with the percentage varied by grade and application. Paperboard used in consumer packaging is a store display item and for these applications, the board is often coated to improve the printing characteristics. The printing requirements for folding carton applications are similar to those for lightweight coated papers and uncoated freesheet. Offset printing blisters and print model from nonuniform coating are major complaints in the coated grades; vessel element pick, in the uncoated offset printing grades. In general the heavy basis weights and thicker coatings provide some flexibility for handling difficult fibers, but the desire to maintain sheet bulk for stiffness makes refining, wet pressing, and calendering less desirable as methods to obtain smoothness.[19] Hardwood pulp improves formation and smoothness which allows the mill to obtain suitable surface properties for printing with less calendering.[20]

Stiffness

The other major requirement of packaging board is stiffness.[21] High board stiffness is needed for product protection and carton stacking strength. In cartons used for liquid packaging, bulging[22] of filled cartons and firm sides needed for gripping the carton are almost as much of a concern as leaks.

Bending stiffness in a solid bleached paperboard can be estimated from Young's modulus of elasticity (E), and the paperboard thickness or caliper (c).[23]

$$S = kEc^3$$

Typical structural paper properties for the eight species are listed in Table V. Comparing the spruces to the southern pines, elastic modulus increases by about 5% for spruce, but caliper (bulk) is reduced by 24%. Since stiffness changes with the cube of caliper, the coarser southern pines will normally give better board stiffness. The southern hardwoods also contribute bulk to the sheet. Referring again to Table III, 90% of the bleached board manufactured in the United States is produced in the south, using the available southern pines and hardwoods.

Solid bleached board is a compromise between box strength and printability, but papermachines using several forming sections are able to improve both properties at once. Multi-ply paperboard using high modulus fiber furnishes on the outer plies and a bulking furnish for the inner ply can improve bending stiffness by 50% over that available using papermachines with a single forming section[24,25]. In this case, the high density needed to improve the elastic modulus of the outer plys also improves printability. Since spruce and fir refine easily to give high modulus papers for the outer plies, and mechanical pulps and waste paper are good choices for bulking inner plies, the success of the three-ply papermachine offers Canada and the Nordic countries the means to challenge the southern kraft paperboard industry[26].

Table V. Fiber properties for structural papers.

Genus	Maximum Bulk cm^3/g	Elastic Modulus kN·m/g	Compression Index N·m/g
Spruce	1.7	8.1-9.0	40-43
W.Hem	1.5	8.8	37-41
D.Fir	2.1	6.5-8.5	31-33
S.Pine	2.1	8.7	36
Oak	2.4		
Gum	2.2	6.5	30-40
Birch	1.5	6.1	36.5
Aspen	1.5		43.0

CORRUGATED BOARD

Corrugated board is an engineered product constructed from paperboard. Combined board properties are influenced by both the manufacturing process and the strength of the linerboard and the medium. The two critical performance tests for linerboard are considered to be compression strength and compressive modulus[27].

Compressive modulus is usually considered to be equal to the modulus of elasticity measured in tensile[28,29] and reported in Table V. Technically, a high elastic modulus requires fibers of low fibril angle[30] and papers of high density[31]. Modulus is also influenced by the drying restraint applied when producing the paper or handsheet[32] and can be improved by any means capable of increasing paperboard density such as improved wet pressing, increased beating,[29] and lower pulp yield[33].

Compression strength is largely a matter of paperboard density[29], but also is influenced by pulp yield[27], double wall thickness, and fibril angle.[34] Under standard pulping and papermaking conditions, species that form higher density

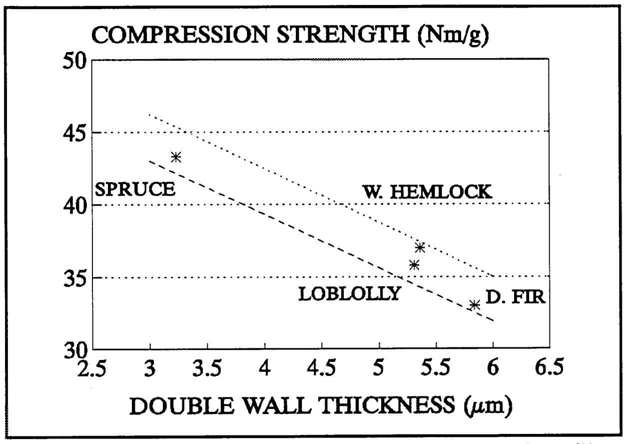

Fig. 1. Compression strength graphed against fiber wall thickness. Top line is for a 5° fibril angle; bottom line, for a 25° angle.[13,34]

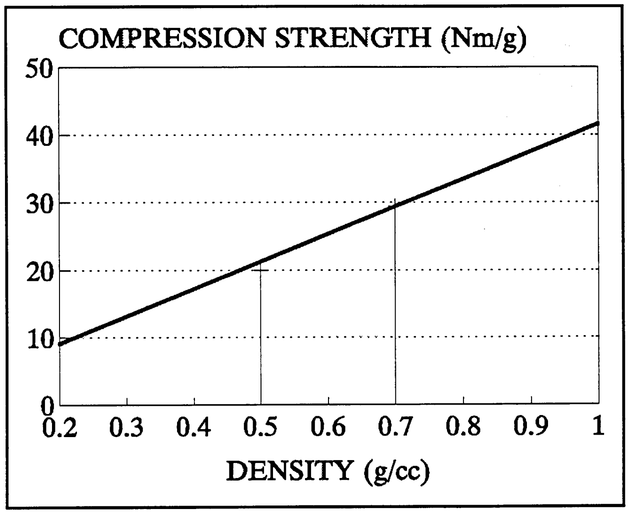

Fig. 2. Paper compressive index plotted against paper density. Normal machine densities fall between 0.5 and 0.7 g/cc.[29]

papers give higher compression strength.[13] In Figure 1, compressive strength is plotted against double wall thickness for the four softwood varieties in the review, spruce gives the best compression strength, followed by western hemlock, loblolly pine, and Douglas fir[34]. Juvenile pines give denser board and higher compression strength than mature pines, and board production would generally benefit from the use of more thinnings and tops.[35]

In practice, over 80% of the kraft board manufactured in the United States is produced in the south. Compressive strength is largely controlled by sheet density under typical paper machine conditions as seen in Figure 2.[29] Southern producers can adjust for the performance characteristics of the southern fibers by improving wet pressing and refining to lower freeness, but it is not possible for the northern producers to adjust for the comparatively high wood costs. For a commodity product such as linerboard, the cost issues are of greater concern than the marginal performance improvement available with thin walled northern fibers.

CONCLUSIONS:

Over the past half century, the paper industry has moved into the southern United States. In recent decades the industry has begun to compete on a global basis. The United States, and particularly the southern United States, enjoy an advantage in wood costs but in most grades, the southern pine fiber has poor performance characteristics and requires greater care in papermaking to compete effectively. In mechanical pulps, the high energy requirements and poor performance characteristics of the southern pines are a serious problem for the industry and U.S. expansion in mechanical pulping capacity has been limited since the late 70s. In coated papers, there are a few southern producers but they must work harder to match the quality of coated paper products manufactured in the northeast and north central states, Canada, and northern Europe.

Paperboard mills with access to Douglas fir and southern pine benefit from the improved paper stiffness using the bulky fibers, but advances in papermaking technology have improved the paperboard quality from thin-walled fibers and northern producers are able to compete with the southern industry. In corrugated containers, the lower cost of southern fibers dominates the market considerations, but quality would improve with a thinner-walled fiber supply.

Like linerboard, wood is a commodity product. The paper industry often adjusts for the performance limitations of some species in paper products to take advantage of the low price and availability. In a quality conscious world, this may no longer be acceptable and the paper and solid lumber industries need to search for methods to improve the performance of their products. Low-density species such as spruce perform well in paper grades but do not work as well in paperboard or lumber. High-density species such as the southern pines give high quality paperboard and construction lumber, but are difficult to use in higher grade paper applications. For many years, the paper industry has sited mills in locations where the local wood supply is most suitable. It can improve its products further by becoming more aware of the influence of tree species and tree age on product performance and selecting for the most appropriate wood source. Mechanical pulp mills have selected for species and wood type for many years. Foreign competitors have begun to control their wood supply to manage fiber properties in their mills.[36] It is time for the U.S. industry to take a more active role and manage the variations in the wood supply to better meet the needs of its customers.

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