Mechanical properties of paper obtained from blends of tropical softwood and hardwood pulps

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ABSTRACT

*The pulping and papermaking characteristics of a tropical softwood (*Pinus caribaea *var.* hondurensis*) and a tropical hardwood (*Gmelina arborea*) were investigated. Trees were harvested from a plantation in Ghana, and chips were delignified by the kraft process. Handsheets (75 g/m^2) were produced from various blends of bleached softwood and hardwood pulps. The results show that hardwood pulp can be substituted up to 50% without compromising sheet mechanical properties. Addition of mineral filler and rosin size to the furnish reduced sheet mechanical properties, especially fold endurance and tear index.*

THE REPUBLIC OF GHANA SPE a significant portion of its scant foreign exchange on imports of paper, paperboard, and allied products. This puts Ghana is in the same position as many other developing countries on the African continent.

One of the benchmarks for assessing the level of development of a country or region is the annual per capita consumption of paper and board. The current estimate for the African continent is about 5.2 kg, the lowest in the world *(1)*. The principal reason for this low consumption is that many African countries lack the foreign exchange required to import pulping and papermaking equipment or to import sufficient quantities of paper and paperboard. There is no doubt that consumption would increase tremendously if paper products were available at reasonable prices.

Several African countries, including Ghana, are establishing plantations of fast-growing wood species in efforts to expand production of pulp and paper. *Gmelina arborea* is a hardwood native to Asia that is being cultivated in several tropical countries because it grows rapidly in such climates. *Pinus caribaea* var. *hondurensis* is a softwood species that grows rapidly under the wet and moist conditions in the tropics. Compared with temperate wood species, this tropical softwood matures quickly and can be harvested as pulpwood at a comparatively young age.

The morphological characteristics and the physical and chemical properties of *G. arborea* and *P. caribaea* spp. have been reported in the literature *(2)*. Bleached pulp characteristics of *G. arborea*, *P. caribaea* spp., and other tropical species have also been reported *(3)*, as has work focusing specifically on *G. arborea (4)*. Yet another study showed that softwood and hardwood pulps produced from these two tropical wood species could be bleached to a brightness of 85–87% *(5)*. However, this level of brightness was achieved at the cost of a 6–10% decrease in mechanical properties. The authors of the present work have established that the brightness of pulps produced from these tropical wood species declines somewhat during the beating process, similar to the behavior observed for pulps produced from temperate wood species.

The results of these previous studies strongly implied that tropically grown *G. arborea* and *P. caribaea* spp. species could be pulped and blended to produce bleached printing and writing grades *(5)*. The laboratory results presented in this report demonstrate that hardwood pulp can be substituted up to 50% without compromising sheet mechanical properties.

RESULTS AND DISCUSSION

There are two compelling reasons for the industry to increase its use of hardwood.

1. Hardwood is cheaper than its softwood counterpart.
2. Increasing the use of hardwood will optimize the industry's raw-material base.

This is an important issue, and several researchers have spoken about the advantages of using more hardwood pulp in the industry *(6–8)*.

Addition of hardwood pulp to a softwood furnish provides a more uniform sheet structure, with the short hardwood fibers filling the spaces between the long tracheid softwood fibers. Hardwood also has an effect on sheet strength.

Mechanical properties of blended pulps

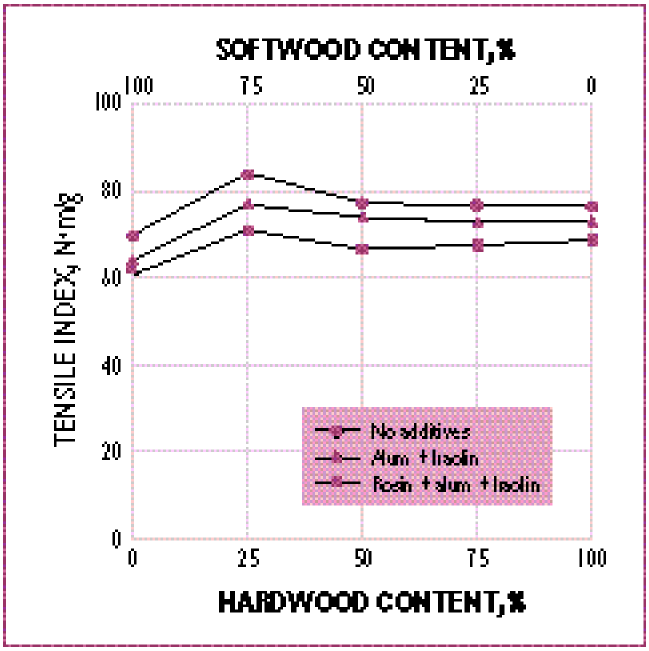
Table I shows the physicomechanical properties of handsheets containing various blends of tropical hardwood and softwood pulps at three levels of chemical treatment:

1. No chemical additives (control pulp)
2. Mineral filler (kaolin) and alum
3. Mineral filler, alum, and rosin sizing.

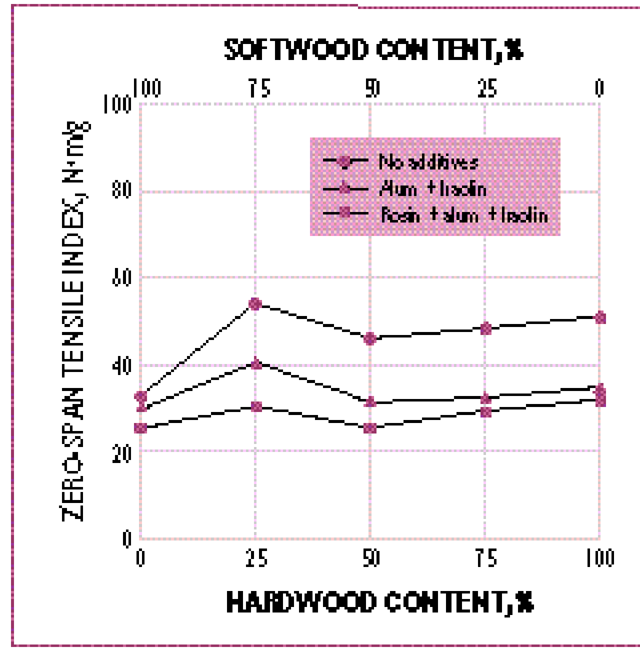
STOCK COMPOSITION		CHEMICALS [b]			HANDSHEET PROPERTIES										
Softwood[c]	Hardwood[d]	Clay[e]	Alum[f]	Size[g]	Apparent density, g/cm^3	Bulk, cm^3/g	Fold endurance, $\log_{10} n$[h]	Burst index, kPa·m^2/g	Tear index, mN·m^2/g	Tensile index, N·m/g	Zero-span tensile index, N·m/g	Ratio of tensile and zero-span tensile indices	Stretch, %	Degree of sizing (Cobb test), g/m^2
No additives														
100	…	…	…	…	0.63	1.59	3.21	4.22	11.1	70.2	33.4	2.10	3.9	…
75	25	…	…	…	0.71	1.41	3.29	7.64	10.0	83.1	55.1	1.51	3.6	…
50	50	…	…	…	0.71	1.40	3.17	4.90	9.5	77.7	43.8	1.77	4.3	…
…	100	…	…	…	0.73	1.37	3.27	5.00	10.1	76.8	46.0	1.67	4.0	…
Alum + kaolin														
100	…	+	+	…	0.71	1.40	2.78	4.02	9.8	64.6	29.8	2.17	3.6	…
75	25	+	+	…	0.70	1.44	3.25	6.71	8.8	77.0	40.2	1.91	3.5	…
50	50	+	+	…	0.73	1.37	3.15	4.71	8.5	74.1	34.3	2.16	4.2	…
…	100	+	+	…	0.77	1.30	3.19	4.81	10.0	73.9	35.7	2.07	3.9	…
Rosin + alum + kaolin														
100	…	+	+	+	0.79	1.28	2.69	3.92	8.4	63.4	25.8	2.45	3.4	41
75	25	+	+	+	0.72	1.44	3.21	6.22	7.3	70.8	29.6	2.39	3.2	42
50	50	+	+	+	0.70	1.40	3.13	4.51	6.6	65.7	27.1	2.42	4.0	40
…	100	+	+	+	0.73	1.37	3.18	4.65	9.8	70.0	33.6	2.09	3.6	16

[a] Handsheets tested at 20°C and 65% RH
[b] + indicates the presence of chemical additive in the sheet
[c] Softwood = *Pinus caribaea* var. *hondurensis*
[d] Hardwood = *Gmelina arborea*
[e] Kaolin, ash content = 6–8%
[f] Aluminum sulfate, 4% on o.d. pulp
[g] Rosin size, 2% on o.d. pulp
[h] *n* = number of double folds

I. Handsheet properties for bleached pulp at various ratios of hardwood–softwood and different combinations of chemical additives [a]



1. Tensile index of bleached-pulp handsheets as a function of SW–HW content at three levels of chemical treatment



2. Zero-span tensile index of bleached-pulp handsheets as a function of SW–HW content at three levels of chemical treatment

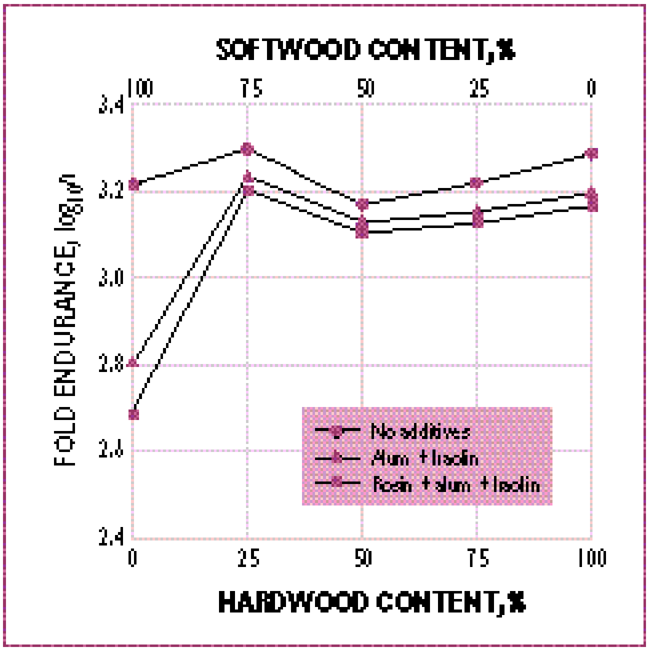
Results for five key mechanical properties—tensile index, zero-span tensile index, fold endurance, tear index, and burst index—are plotted as functions of hardwood-softwood content in **Figs. 1–5**, respectively. These results demonstrate that addition of hardwood pulp increased sheet mechanical properties, with the exception of tear index (Fig.4).

The results in Figs.1-5 also show that the chemical treatments with kaolin, alum, and sizing reduced sheet strength properties. Notwithstanding the many positive properties of a mineral filler, its addition to the stock furnish has some negative effects on sheet properties *(9)*. The filler particles that occupy the spaces between the plant fibers increase sheet porosity (and thus its air permeability) and hinder the formation of strong interfiber bonds. The coordination bonds per the ions of aluminum cannot compensate for the reduction in the number of hydrogen and other types of strong bonds.Hence,any sheet containing a mineral filler usually shows a reduction in mechanical strength. This is particularly apparent in Fig.3,where sheets containing kaolin show a dramatic reduction in fold endurance. Increasing the filler content leads to a correspondingly weaker sheet. Moreover, the degree of fluffing increases with increasing filler content.

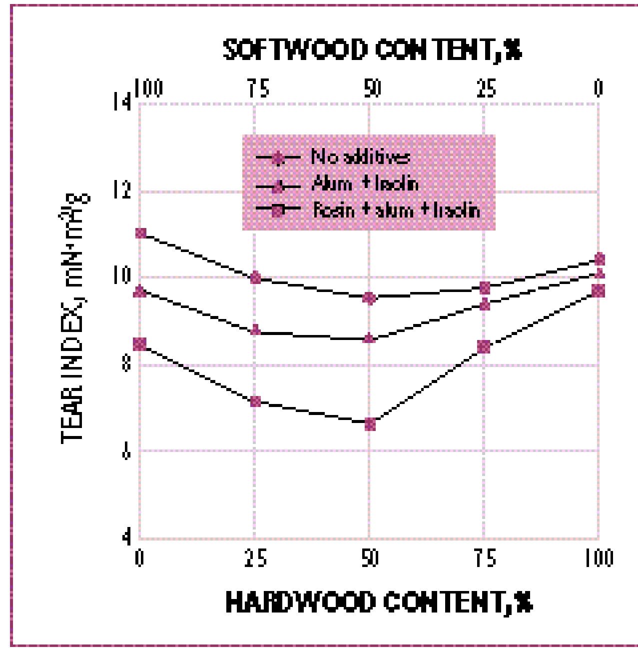
Figures 1-5 also show that sheet strength was reduced when a rosin size was added to the furnish. Generally, the effect of sizing on sheet properties cannot be predicted by a single variable. The effect depends on the type of sizing material, the quantity applied,and the method of application. (Size can be added to the stock furnish or applied to the sheet surface.) Addition of small quantities of rosin size to the stock furnish does not have a noticeable effect on the indices of sheet mechanical properties. However, if more than 1.5% size is added to the furnish, there is a decrease in sheet mechanical properties and a corresponding increase in porosity.

As seen in Figs. 1-5, the rosin-sized sheets suffered a reduction in mechanical strength compared with the unsized sheets. This is probably because the negative effect of sizing—the rosin particles increase sheet porosity—outweighs the positive effect of the bonds established between cellulose fibers by way of coordination with aluminum ions. The increased sheet porosity reduces deformation when the sheet is immersed in water. However, even when paper has been treated to give it a certain degree of hydrophobicity, internal sizing with rosin does not confer any degree of oil repellency. Indeed, rosin size makes the paper a little more oil receptive.

It is clear from the data in Table I that the best degree of sizing (Cobb test = 16 g/m^2) was achieved when the stock furnish contained only the hardwood *G. arborea*. The sizing values for the other composite mixtures of the furnish are average (Cobb test = 40-42 g/m^2).



3. *Fold endurance of bleached-pulp handsheets as a function of SW–HW content at three levels of chemical treatment*



4. *Tear index of bleached-pulp handsheets as a function of SW–HW content at three levels of chemical treatment*

KEYWORDS

Bleached pulps, chemical properties, Ghana, hardwood pulps, kraft pulping, mechanical properties, paper properties, physical properties, Pinus caribaea, *rosin size, sizing, softwood pulps, tropical atmospheres.*

Tensile index

The main qualities required of printing and writing grades are difficult to define, according to Flyate *(9)*. First, different printing techniques impose correspondingly different quality demands on the sheet. Second, even if clear quality demands can be formulated for a given application, the printing properties of paper cannot be expressed by a single variable or index. It is generally accepted that sheet quality is characterized by a complex system of indices that guarantee high-quality printing for any type of printing method.

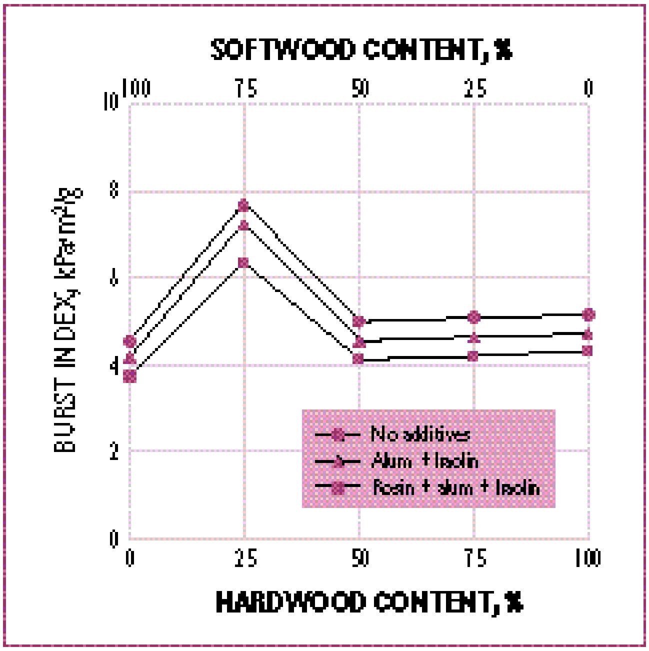
The ultimate strength of plant fibers is artificially evaluated as zero-span tensile strength.This is the tensile strength of paper as measured at zero distance between the jaws of a conventional tensile testing machine.

The strength of a sheet of paper depends not only on the inherent strength of the original fibers, but also on the degree of bonding between the fibers. Hence, Clark *(10)* is of the view that the degree of bonding between fibers could be evaluated by the ratio between tensile index and zero-span tensile index. Table I shows that the highest value for the ratio between tensile index and zero-span tensile index was 2.45 for the sheet prepared solely from softwood. This is just slightly higher than the ratio obtained for the furnish consisting of 50% softwood and 50% hardwood pulps,which was 2.42.

Zero-span tensile index depends to a very small extent on fiber length, fiber coarseness, and sheet density. However, these factors significantly affect conventional tensile index. Thus it follows that the ratio between conventional and zero-span tensile indices cannot be considered as a dependable measure of a pulp's cohesive capacity. Nevertheless,the ratio serves as a useful quality-control index that can be used to make deductions about the relative influence of the factors that affect bonding *(11)*.

A strip of paper clamped in the jaws of a conventional tensile testing machine ruptures at a weak place or point *(9)*. In most cases,the point of rupture is not the fiber itself but, rather, the bonds between fibers. As the bonds break, the unbroken fibers on opposite sides of the rupture are pulled apart.Only a portion of the fibers in the cross direction of the rupturing sample experience a break.

Since the rupture process principally involves the breaking of interfiber bonds, tensile strength is primarily a measure of bond strength. The strength of the individual fibers, as measured by the zero-span method, has only a small effect on tensile strength. However, fiber strength does affect the main indices describing sheet mechanical



5. Burst index of bleached-pulp handsheets as a function of SW–HW content at three levels of chemical treatment

properties (especially the tear index). Fiber strength also has a substantial influence on fold endurance, burst index, and the stretch at breaking point.

CONCLUSIONS

The results of this study demonstrate that up to 50% hardwood pulp (*G. arborea*) can be substituted in a softwood furnish (*P. caribaea*) without reducing sheet mechanical properties. Indeed, some of the indices for sheet strength at 50% hardwood substitution were higher than for sheets made from 100% softwood. The study results also confirm that sheet mechanical properties decline when mineral fillers or size are added to the furnish. This is especially true of fold endurance and tear index.

Research work carried out by Russian and other scientists throughout the world has established limits for hardwood substitution in key paper grades. The substitution limit is 50–60% for typographic, offset, and intaglio printing papers, while the limit for writing papers is 40–60% *(12, 13)*.

EXPERIMENTAL

Bleached pulp from *P. caribaea* var. *hondurensis* was beaten to a freeness of 30–32°SR. Bleached *G. arborea* was beaten to 40–42°SR. The freeness of the blended pulps was slightly higher than the norm in Russia for mixtures of softwood and hardwood pulps.

Handsheets of basis weight 75 g/m^2 were made on a laboratory sheet former (Rapid-Köthen, Germany) using varying amounts of bleached softwood and hardwood pulps. One set of handsheets was produced from 100% fibrous material without any additives. The second set of handsheets contained kaolin (6–8% ash content) and 4% aluminum sulfate (based on o.d. mass). The third and final set of handsheets was the same as the second set, except it also contained 2% rosin size (based on o.d. mass).

Our investigations did not show any unexpected results in handsheet properties. It is well known that filler addition leads to a corresponding decrease in sheet mechanical properties. The effect is intensified when both filler and size are added to the furnish. **TJ**

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