HESPERALOE FUNIFERA — AN EXCELLENT REINFORCEMENT FIBER FOR MECHANICAL PAPER GRADES

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ABSTRACT

Hesperaloe funifera*, a frost-tolerant nonwood plant with long, slim fibers, was pulped by the soda and alkaline sulfite processes. The resulting soda pulp was evaluated as a replacement for softwood kraft in a furnish simulating supercalendered A-grade (SCA) paper. It was found that 25% kraft could be replaced by 10%* Hesperaloe *and 15% mechanical pulp at equivalent strength. There was no need to refine the* Hesperaloe *pulp before its use.*

INTRODUCTION

Many nonwood fibers are used or have been proposed as sources of pulp. In general, these nonwood fibers are either agricultural residues (e.g., wheat or rice straw) or are grown specifically for the use of their fibers (e.g., bamboo, hemp, and sisal) *(1)*.

Mechanical paper grades include the range of grades from newsprint to lightweight coated (LWC) paper. Fifty years ago, most newsprint was made with stone groundwood (SGW) pulp. Newsprint could not be made from 100% SGW because it was not strong enough. Thus a reinforcement fiber such as softwood kraft was added, typically at 15–20% content. In the 1960s, many high yield sulfite (HYS) plants were built at newsprint mills *(2)*. HYS has a yield of about 70% and can be manufactured at a lower cost than kraft pulp. Typically, newsprint was made with 70% SGW and 30% HYS.

Today, most newsprint is made with thermomechanical pulp (TMP), deinked pulp, or a mixture of both. Little or no reinforcement pulp is required. However, many higher-value mechanical paper grades, such as SCA (supercalendered grade A) and LWC, especially at lower basis weights, require addition of softwood kraft reinforcement pulp. SCA is supercalendered paper with 20–30% filler clay content. This filler clay debonds the sheet, and 15–25% reinforcement pulp is required to maintain a sufficient tensile strength in the sheet for machine and pressroom runnability. In LWC grades, the reinforcement pulp is required not only because of the low basis weight and some filler content, but also to make the base sheet strong enough to withstand the coating process. For a blade-coated and supercalendered sheet made with SGW pulp, 40–50% reinforcement pulp may be required, while for an LWC sheet with a metering roll coater and soft-nip calender on-machine, the reinforcement pulp content can be as low as 20% *(3)*.

The price of softwood kraft has been near historical lows recently, but purchased kraft pulp can still cost 3–5 times as much as a mechanical pulp manufactured onsite. As demonstrated by the development of HYS and TMP pulps, the industry has been steadily working to develop manufacturing methods that require less reinforcement pulp.

One fiber property that results in a good reinforcement pulp is a high aspect ratio, i.e., the ratio of fiber length to fiber width. The fiber properties of several nonwood and wood species are presented in **Table I**.

Fiber	Mean length, mm	Mean width, µm	Aspect ratio, L/W
Flax bast fiber	30	20	1500:1
Hemp bast fiber	20	21	950:1
Abaca	6.00	22	270:1
Hesperaloe funifera	3.20	15	215:1
Sisal	3.03	17	180:1
Cotton linters	3.50	21	165:1
Kenaf bast fiber	2.74	20	135:1
Wheat straw	1.48	13	110:1
Jute	2.00	20	100:1
Black spruce	3.00	40	75:1
Aspen	1.00	26	38:1

Table I. Comparison of fiber dimensions for several nonwood and wood species.

Fibers with a high aspect ratio, such as abaca or flax and hemp bast fibers, require special processing techniques to avoid entangling the fibers. In addition, these fibers can be expensive due to the cost of separating the long fibers from the plant and the resulting reduction in yield.

Black spruce, a northern softwood fiber with an aspect ratio of about 75:1, is widely recognized as an excellent reinforcement fiber. Other potential candidates for reinforcement fibers are cotton linters and sisal.

Cotton linters are the short fibers left on the seed after removal of the cotton staple. They have a reasonable fiber length of 3.5 mm and an aspect ratio greater than black spruce, but they are generally available only as a waste product from seed oil mills and cotton gins, at a relatively high price.

Sisal *(4, 5)* is a plantation fiber used mostly for cordage. However, sisal can also be pulped and used in papermaking, since the fibers are relatively long. Sisal plantations currently exist in Brazil, Kenya, and Tanzania. An unpublished study *(5)* showed that sisal is a better reinforcement pulp than softwood kraft (SWK), and a mixture of 65% SGW and 35% SWK could be replaced by 81% SGW, 10% SWK, and 9% sisal pulp.

In 1985, the James River Corp. (now the Fort James Corp.) was evaluating the possibility of importing a hybrid sisal fiber from Brazil for use in specialty papers. Due to possible political risk and the transportation costs of importing fibers from Brazil, James River approached the University of Arizona's Office of Arid Land Studies in order to determine whether sisal could be grown competitively in the United States. Unfortunately, sisal is not frost tolerant, and no part of the continental United States is free of frost year-round. Thus the search was begun for a species with fiber qualities similar to sisal but with frost resistance *(6)*.

An exhaustive search of some 62 species in the Agavaceae family revealed two frost-resistant species with excellent fiber quality: *Hesperaloe funifera* and *Hesperaloe nocturna (7)*. These *Hesperaloe* species are native to northern Mexico and are commonly used as ornamental plants. Over the next several years, the University of Arizona studied various techniques for growing *Hesperaloe funifera* as a plantation crop. Issues such as irrigation, fertilization, weed control, plant spacing, propagation, and harvesting cycle have been discussed by McLaughlin *(6, 8)*.

One of the issues that has been studied by various parties, but never published, is a pulping recipe for *Hesperaloe.* James River obtained a patent covering the use of *Hesperaloe* chemical pulp in tissue and towel products, but it did not specify the chemical pulping method to be used *(9)*. Wong and McLaughlin recently reported on a pulping process using potassium alkaline sulfite *(10)*:

- A high unbleached brightness of up to 78% ISO
- Exceptional strength
- Possibility of using *Hesperaloe* as a reinforcement pulp without any refining.

In this study, we report on the properties of soda/anthraquinone (AQ) and alkaline sulfite pulping of *Hesperaloe funifera*. In addition, we report on the properties and comment on the economics of using *Hesperaloe funifera* pulp as a reinforcement pulp.

EXPERIMENTAL

Fiber

Hesperaloe funifera fiber — roller-milled and air-dried — was provided by the University of Arizona.

Soda/AQ pulping

Hesperaloe fiber was preweighed and placed in a minidigester basket. Pulping liquors contained varying levels of sodium hydroxide and an AQ dosage of 0.1% on pulp. The temperature was raised to 155°C over 70 min and maintained at this level for a further 40 min. The liquor to raw-material ratio was 7:1, and the pulping liquor was continuously recycled through the digester. The pulp was disintegrated after the cook and washed with hot water until a clear filtrate was obtained.

Alkaline sulfite pulping

Hesperaloe fiber was preweighed and placed in the digester basket. Cooking liquors contained varying amounts of sodium hydroxide and sodium sulfite. The temperature was raised to 155°C over 100 min and maintained at this level for a further 40 min. The pulp was disintegrated after the cook and washed with hot water until a clear filtrate was obtained.

Handsheet studies

Handsheets were prepared according to TAPPI test methods, using a British handsheet machine. Appropriate amounts of stone groundwood and refiner mechanical pulp (obtained from Abitibi-Consolidated, Jonquière, PQ), *Hesperaloe* pulp (prepared in the lab), water-washed clay (obtained from ECC International), and bleached northern softwood kraft pulp (refined to a freeness of 450 mL CSF) were added to obtain the desired mixtures. Ash content was measured at 500°C to determine the filler content. A retention aid was used in the handsheets containing clay, to aid in retention and even the *z*-distribution of the clay. Bentonite clay (Organosorb) was used at 3 kg/metric ton, and polyacrylamide (Organopol) was used at 200 g/metric ton. Both were obtained from Ciba Specialty Chemicals.

RESULTS

Soda/AQ pulping

Hesperaloe fibers were initially pulped using conditions of 18% NaOH, a cooking time of 60 min, and a temperature of 170°C. **Table II** shows the physical properties of the *Hesperaloe* pulp before beating and after 500 revolutions in a PFI mill. Results for a softwood kraft pulp beaten to similar freeness levels are included for comparison. The results show that the burst and tensile strength of the unbeaten *Hesperaloe* pulp are quite high, suggesting that this pulp could be used as a reinforcement pulp without refining. This is an important finding, since many paper mills that produce mechanical paper grades have little or no capacity available for refining their reinforcement pulp.

	Unbeaten soda/AQ *Hesperaloe*	Beaten soda/AQ *Hesperaloe*	Unbeaten kraft softwood	Beaten kraft softwood	Unbeaten alkaline sulfite *Hesperaloe*
Freeness, mL CSF	512	370	621	380	603
Burst index, kPa·m²/g	9.16	9.15	2.49	8.10	11.6
Tear index, mN·m²/g	17.4	13.4	23.8	11.1	22.6
Tensile index, N·m/g	104.4	108.6	40.9	101.6	130.1

Table II. Comparison of* Hesperaloe *and softwood kraft pulps.

A series of pulping optimization experiments revealed that a lower kappa number could be obtained by increasing the NaOH dosage to 20%. At a NaOH dosage of 20%, the temperature and the cooking time could be reduced to 155°C and 40 min, respectively, without affecting the kappa number. The pulping yield was typically between 40% and 45%.

Alkaline sulfite pulping

Initial studies of alkaline sulfite pulping of *Hesperaloe* raised concerns about the presence of uncooked, shivelike material in the pulp. A number of experiments were carried out to determine how to eliminate this problem.

Table III shows the effect of alkalinity on shive level. The main factor appears to be the NaOH dosage, which must be maintained at 19.4% or higher (under the chosen cooking conditions) to prevent shives. The shive-free pulps also had a residual NaOH level of 1.5% or higher. Raising the dosage of sulfite did not appear to have an effect on the shive level.

Pulp sample	SO_2 , %	NaOH, %	NaOH remaining, %	Shive level
F	0	25.8	7.2	None
J	0	19.4	2.1	None
K	5	19.4	1.5	None
H	7.5	16.1	1.0	High
AA	10	18.1	1.5	High
AB	7.5	16.1	1.0	Very high
N	10	12.9	0	Very high

Table III. Effect of chemicals on shive level.

The *Hesperaloe* fibers were washed with hot water prior to pulping in order to see if this affected pulping efficiency. The results in **Table IV** indicate that hot-water washing results in less shives than unwashed pulps under identical pulping conditions. Brightness increased significantly, but the pulping yield decreased. The prewashing removed about 30% of the dry weight of the plant. This soluble material presumably consumes pulping chemicals if it is not removed by prewashing.

	SO_2 , %	NaOH, %	No wash	Prewash
			Sample H	Sample X
Brightness, % ISO			48.3	50.3
Yield, %			43.4	38.2
Shive level	7.5	16.1	High	None
			Sample Q	Sample U
Brightness, % ISO			36.6	46.5
Yield, %			49.0	42.8
Shive level	0	12.9	Very high	Very high
			Sample R	Sample S
Brightness, % ISO			34.7	51.1
Yield, %			43.7	38.4
Shive level	0	19.4	Low	None

* Pulping conditions: 155°C, 40 min

Table IV. Effect of prewashing on* Hesperaloe *alkaline sulfite pulp *.

When the strength properties of the best alkaline sulfite pulp are compared with the soda pulp in Table II, it can be seen that the sulfite pulp has better strength properties. In comparison with the unbeaten soda pulp, the burst, tear, and tensile indices were higher by 27%, 30%, and 25% respectively.

Handsheet studies

Since the object of our study was to determine the benefits of using *Hesperaloe* pulp as a reinforcement pulp, handsheets were made to simulate an SCA furnish. A typical furnish contains about 25% softwood kraft, 25% clay, and 50% mechanical pulp. In this case, the mechanical pulp was an equal mixture of stone groundwood and refiner mechanical pulp. It was found that using 25% *Hesperaloe* soda pulp gave an SCA sheet with much higher strength properties. Thus, a series of handsheets was made using 20%, 15%, and 10% *Hesperaloe* content — substituting the remainder with mechanical pulp — in order to see if a furnish with equal strength to the kraft-containing control sample could be obtained.

The results in **Table V** show that a sheet with 10% *Hesperaloe* reinforcement pulp had properties comparable with the control containing 25% softwood kraft. This means that 1 metric ton of

Hesperaloe pulp could replace 2.5 metric tons of softwood kraft pulp. Given the results in Table II — with the alkaline sulfite pulp showing higher strength than the soda pulp — this replacement ratio could probably be further improved by optimizing the pulping recipe.

	REINFORCEMENT PULP				
	25% kraft	**25% *Hesperaloe***	**20% *Hesperaloe***	**15% *Hesperaloe***	**10% *Hesperaloe***
Pulp components					
SGW, %	25	25	27.5	30	32.5
TMP, %	25	25	27.5	30	32.5
Ash, %	24.21	23.81	25.16	25.43	23.82
Handsheet properties					
Brightness, % ISO	65.6	52.5	54.9	56.9	58.7
Basis weight, g/m^2	61.2	63.0	62.2	62.6	63.1
Density, g/cm^3	0.52	0.53	0.52	0.51	0.49
Burst index, $kPa \cdot m^2/g$	1.72	3.18	2.73	2.14	1.82
Tear index, $mN \cdot m^2/g$	6.73	7.71	8.41	6.79	5.60
Tensile strain, %	2.73	2.85	2.74	2.73	2.58
Tensile index, $N \cdot m/g$	29.4	42.0	36.7	34.0	31.1

* All properties measured on uncalendered handsheets. Softwood kraft was bleached (89% ISO brightness), while the *Hesperaloe* pulp was unbleached (32% ISO brightness).

Table V. Properties of SCA furnish with* Hesperaloe *or softwood reinforcement pulp *.

CONCLUSIONS

The results show that *Hesperaloe* is a much better reinforcement pulp for mechanical pulp grades than softwood kraft. While this is not the only reinforcement pulp that performs better than softwood kraft, it is the only one we know that:

- Is frost tolerant and thus cultivatable in temperate zones
- Contains a single fiber type, with no separation steps necessary prior to pulping.

The reinforcement properties of the *Hesperaloe* pulp can be explained by the dimensions of the fiber. Since a *Hesperaloe* fiber is much more slender than a softwood fiber such as black spruce, the number of fibers in the same weight of pulp will be higher, providing more fiber surface area for bonding.

Given the ease of harvesting, a pulp yield comparable with wood, and the lack of necessity to do any fiber separation, we believe that the cost of pulping *Hesperaloe* fiber could be comparable with that of softwood. We estimate the raw material cost at US$ 47/metric ton, which is competitive with the cost of wood.

Using the data in Table V, it is possible to estimate the potential savings in paper manufacturing costs when 10% *Hesperaloe* is substituted for 25% softwood kraft. For example, assume that the price for kraft pulp is US$ 550/metric ton and the cost of mechanical pulp is US$ 200/metric ton. In this case — assuming that *Hesperaloe* pulp can be produced at the same cost as kraft pulp — substituting 10% *Hesperaloe* fiber and 15% mechanical pulp for 25% kraft would result in a savings of US$ 52.50 per metric ton of paper. There may also be additional advantages to using *Hesperaloe*, since the increased mechanical pulp content would likely result in better opacity, formation, and printing properties.

The cultivation issues have been well addressed *(6, 7, 8)*, and the harvesting issues have also been analyzed *(11)*. The remaining issues are economic, including startup costs for a plantation and the capital costs of building a pulp mill. These costs would be very site specific, depending on factors such as the cost of chemical recovery and environmental compliance. The results of this study suggest that in some parts of the world — for instance, where straw is chemically pulped and softwood kraft is being imported — a straw-pulping plant might easily be converted to *Hesperaloe*.

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