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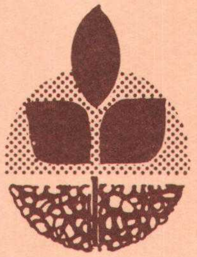
Pulping Characteristics of Willamette Valley Grass Straws



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ABSTRACT

A comprehensive pulping study has been made of straw from annual ryegrass (*Lolium multiflorum* Lam.) grown in the Willamette Valley of Oregon. Unbleached soda pulps with yields of 50-55 percent form clean, strong, and well-bonded sheets and could be blended with softwood pulps to improve the tensile and bursting strengths of paper from softwood pulp, as well as the smoothness and formation. Soda pulps with Kappa numbers less than 30 can be bleached by conventional techniques to brightnesses between 85 and 90 percent and could be used for replacing a hardwood pulp. A pilot plant trial showed the feasibility of producing a high-quality bond paper using bleached straw pulp and a softened pulp.

Pulp for corrugating medium may be produced from annual ryegrass straw by the neutral sulfite semichemical (NSSC) process. Yields are comparable to those from wood, 65-75 percent, and strength and performance characteristics of the medium are nearly on a par with commercial medium from NSSC hardwood pulp. This also was shown in a pilot plant trial.

Straw may be pulped in stalk form, chopped, pelletted, or cubed. Densification simplifies problems encountered in transportation, storage, and pulping, but economics may not permit such a step. Pelletting causes severe losses in pulp strength, but cubing does not.

Straws of other grass species, such as fescue, bent, and blue grass, have been pulped, but only fescue is equal to annual ryegrass in strength properties. No straw pulp has the tearing strength of a softwood kraft pulp, such as Douglas fir kraft.

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PULPING CHARACTERISTICS OF WILLAMETTE VALLEY GRASS STRAWS

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INTRODUCTION

Straws of various types have been used as sources of papermaking fibers for many centuries, and in fact, straw was one of the original sources of fiber for the manufacture of paper. Today, in those countries short of wood, straw still is used widely for making paper. For many years, straw also was the source of pulp and paper in the United States, but since the end of World War II, all straw mills in this country have been closed or converted to use of wood for manufacture of pulp. The many reasons for this change include limited season of harvest, biodegradability of straw in storage, and certain difficulties in manufacturing straw pulp and paper. All are related to economics, and most mills have converted to wood primarily because it is cheaper to manufacture pulp from wood than from straw.

Large quantities of straw are available in the Willamette Valley of Oregon. This straw is generated as a residue from production of grass seed, a major agricultural enterprise in this area (1). During late summer, about one million tons of straw have been burned annually to rid farmers of this unwanted crop residue. Resultant air pollution has generated considerable public criticism, and the State Legislature has proclaimed a ban on field burning after 1975. In the interim, it is hoped that other uses for the straw may be developed and thereby help solve the problem for grass seed farmers. If all or part of the straw could be utilized for pulp and paper, this could provide an economically useful way of disposing of this residue. There also are other possible uses for straw, such as for cattle feed, hardboard, and chemicals.

In 1969, the Department of Agronomic Crop Science of Oregon State University requested the Forest Research Laboratory to conduct pulping experiments on some grass straws of the Willamette Valley, because we have basic pulping experience. Application of fairly simple pulping methods, normally used in pulping wood, indicated that straw pulps could be produced readily, and that these pulps had good properties (2). We found that straw pulp could be produced readily in acceptable yields, and that paper produced from these pulps was surprisingly strong. Based on this preliminary experience, the Forest Research Laboratory has performed about three years of research work on pulping of straw residues from grass seed production in the Willamette Valley. This report describes results of the work in laboratory and pilot plant.

As mentioned, straw is an ancient and still current source of fiber for papermaking in the world. Many different types of straw are being used, among them bagasse (the residue from sugar produced from cane), rice, bamboo, and various other types of cereal and grass straws. Grass straw is one of the lesser materials in this category, however, and little information has been published on its pulping. Nothing was available concerning Willamette Valley grass straws.

Even though straw has fallen into disfavor in the United States for pulping, interest has been renewed recently in pulping of agricultural residues and nonwoody crops in general. Both of the previous Alkaline Pulping Conferences, held by the Technical Association of the Pulp and Paper Industry in New Orleans in 1970 (8), and in Houston (3), sponsored special sessions on nonwoody materials. Much of the substance of these conferences has dealt with pulping of bagasse. World-wide, bagasse is the major nonwoody material used for pulp and paper, but it has many disadvantages. For example, 30 percent of bagasse is pith, which is useless for pulping. Other straw pulps have advantages over the pulp from bagasse, because larger fractions of the straws can be utilized in pulping.

Straw must be considered as a raw material competitive with wood for pulping in the United States today, because there is presently no shortage of wood for this purpose. Many economists, however, predict a shortage of wood for all uses within the next 20 years, and most likely by the year 2000 we will be using all the wood that is available in the United States for various forest products (4). Hence, consideration of alternative sources of fiber should be an important part of our research and planning for the future.

Among disadvantages associated with straw pulps, the following are most critical:

Low pulp yields, both unbleached and bleached, compared to wood.
High bulk of straw, making for difficult and expensive procedures in handling, storage and digester packing.
Low freeness (slow water drainage) of the straw pulp, causing handling problems during pulping, bleaching, and papermaking.
Weak paper properties, particularly low tearing strength.
High silica content of the straw, which contaminates alkaline liquors and interferes with recovery of waste liquor.

The work we have performed has answered some of these criticisms with relation to grass straw, and these points will be discussed at the end of this report.

The species of grass utilized in the majority of our experiments has been annual ryegrass (*Lolium multiflorum* Lam.). This is the major species of grass grown for seed in the Willamette Valley, with an estimated 300,000 to 500,000 tons of straw residue available each year (5). There are other species that produce straws of considerable tonnage, however, and these also will be reported in this document.

LABORATORY RESEARCH WORK

Densification of Straw

As mentioned, the high bulk of straw is a serious drawback to its utilization. This feature entails large facilities for moving and storage before the straw can be processed, and also necessitates large and bulky equipment for processing. In early stages of this project, annual ryegrass straw was received in bales with individual stalks ranging in length from several inches to three feet. Handling this loose material was cumbersome, and charging the digester was difficult. For example, one kilogram of wood chips (dry basis) can be charged easily in our 12-liter digester, but not more than 800 grams of loose straw could be charged, even with considerable tamping and compressing. We found that by cutting the stalks in a hammermill to an average length of 1-2 inches, the digester charge could be increased by 10-15 percent by weight. Most of the basic work on soda and draft pulping was performed on chopped straw prepared in this fashion.

The Agricultural Engineering Department at Oregon State University had been investigating various methods of densifying straw (6). This included chopping straw into short segments and compressing them into various sizes and shapes. Among the more promising methods was the cubing of straw, whereby the straw is compressed into cubes about one inch on a side (Figure 1).

Straw cubes have many analogies to wood chips. They can be produced, transported, and stored in bulk form similarly to wood chips, depending on the conditions of manufacture, which is an advantage.

Figure 1. Straw cubes and pellets.

The main problem that we foresee with cubes is swelling when they contact water. They immediately swell to several times their compressed dimensions, and if this were to happen in a pile or a rail car, a swollen mass of straw would result that would be nearly impossible to salvage. Also, if a digester were packed tightly with cubes, addition of the liquor might result in swelling that could channel the liquor flow through the straw and cause nonuniform pulping. There is, however, a shrinkage effect when straw is wetted with alkaline solution, and this might counteract the swelling effect of the water. We have pulped batches of cubed straw, both in laboratory and in pilot plant digesters, and have found no problems with the pulping action. Consequently, we concluded that this is a feasible approach to straw densification.

We found no significant differences between strength properties of pulp from cubed straw and pulp from chopped straw. Pelletted straw, however, is significantly weaker in physical strength, compared to pulps from either chopped or cubed straw. The explanation is that the pellets were quite small, about ¼ inch in diameter and from ¼ to ½ inch long, and physical attrition of the straw during pelleting permanently damages the inherent fiber structure. Results of the testing are summarized in Figure 2.

We think that cubing straw for pulping is feasible if the economics are favorable. Cubing significantly reduces the bulk of straw, compared to bales or loose straw, and permits straw to

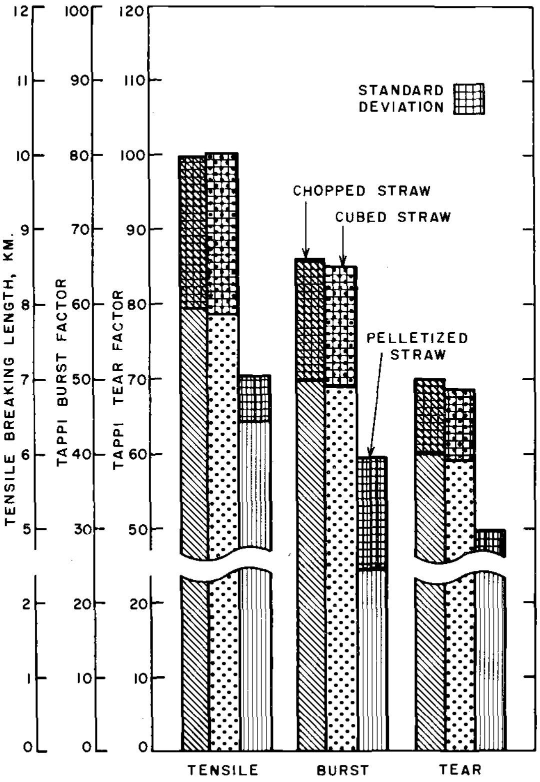

Figure 2. Comparison of strength of paper prepared from pulps of chopped, cubed, and pelletted ryegrass straw.

be handled and transported with equipment that is available today for bulk handling of wood chips and residues. Straw could be stored in cubed form in large piles similar to chip piles, provided that these piles are protected from water. Packing cubed straw in a digester to a bulk density equalling or exceeding that of wood chips is no problem, and the resultant pulp does not suffer in strength properties from pulp from chopped straw. Pelletting should be avoided, however, because it permanently damages the straw fibers and results in weaker pulp.

Bomb Pulping

Soda Pulping of Annual Ryegrass

The majority of the experimental work on annual ryegrass straw has been with soda pulping, that is, using sodium hydroxide as the only pulping chemical. There are several reasons for this:

1. The soda process has been utilized traditionally for straw cooking.

2. Use of sodium hydroxide (NaOH) alone results in an essentially odorless pulping process, as contrasted to the kraft odor from using sodium sulfide (Na_2S) as well as NaOH.

3. Soda black liquor can be recovered as well as kraft black liquor, thus avoiding stream pollution.

4. Our tests showed that there was no overall advantage in strength to kraft pulp over soda pulp.

Results of the soda pulping in bombs are summarized in Figures 3 through 6. In general, the data follow the classical pulping parameters, that is, increased time, temperature, and chemical concentration cause more rapid pulping of the straw. Cooks made with low amounts of sodium hydroxide become acid-type cooks, because the alkali charged is insufficient to neutralize acids released during pulping. The maximum yield at 2 percent alkali is the result of the buffering action of small amounts of alkali, as compared with acid conditions of the pure water cook. With increasing alkali, the direct pulping action of the alkali increases, which results in lower yields at constant time and temperature (Figure 3).

Differences were small in Kappa numbers of the pulp relative to the variations in time and temperature in pulping (Figure 4). The Kappa number, then, depends primarily on the alkali added to the cook.

Kappa numbers of the low-temperature pulps are lower than those of the high-temperature pulps, at constant yield (Figure 5). The explanation for this may be the greater amount of lignin condensation that occurs in the high-temperature cooks. Hence, all subsequent cooks were conducted at 320 F.

At constant yield, shorter cooks yield pulps with lower Kappa numbers than longer cooks, another process benefit (Figure 6). In summary, a 60-minute cook at 320 F was adequate for pulping the straw, with a maximum degree of lignin removal.

Kraft Pulping of Annual Ryegrass Straw

An analogous series of bomb cooks was conducted by the kraft process using liquor of 22 percent sulfidity. The data have been condensed into Figures 7 and 8. Figure 7, showing the relation between active alkali and unscreened yield, suggests that the kraft process is more efficient on a time basis than the soda process. Again, minor differences in yield exist between 320 F and 360 F for the kraft cook.

Figure 8, showing the relation between yield and Kappa number, indicates that in the normal range of pulping, with yields from 40 to 50 percent, there is little difference between the Kappa numbers of kraft and soda pulps at constant yield. In the semi-chemical range, the soda process produces pulps containing less lignin than pulps from the kraft process. Whether

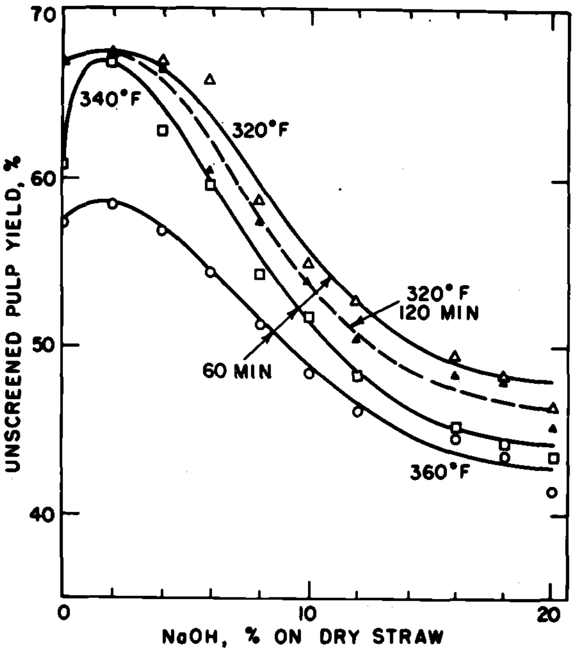

Figure 3. Relation of pulp yield to percentage of alkali in pulping grass straw.

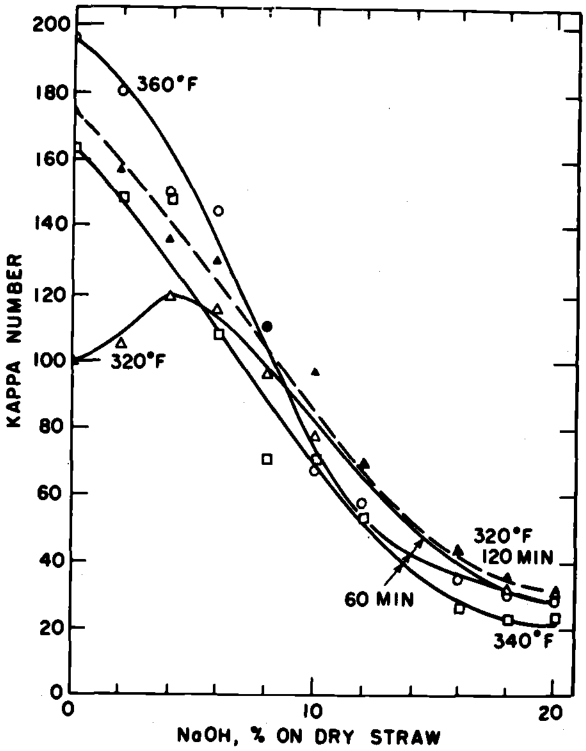

Figure 4. Relation of Kappa number to percentage of alkali in pulping grass straw in small bonbs.

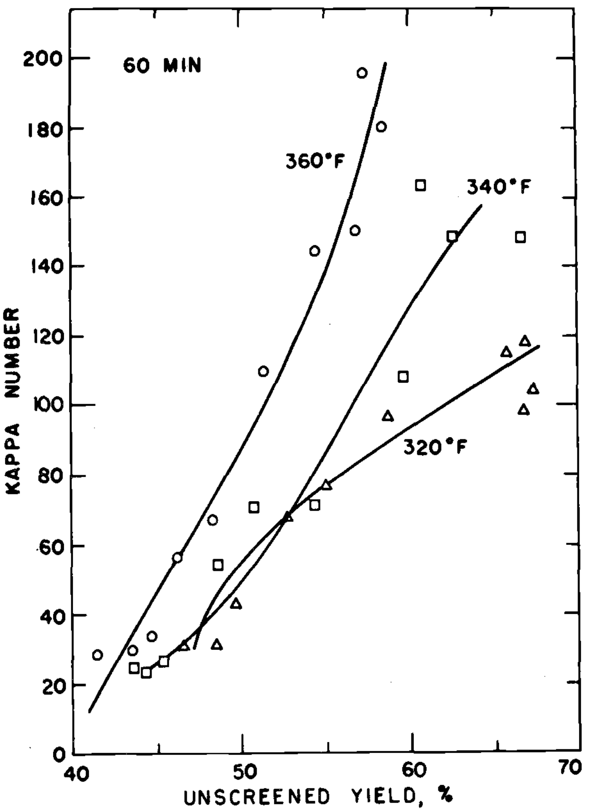

Figure 5. Relations among cooking temperature, yield, and Kappa number of ryegrass straw soda pulped for 60 minutes in bombs.

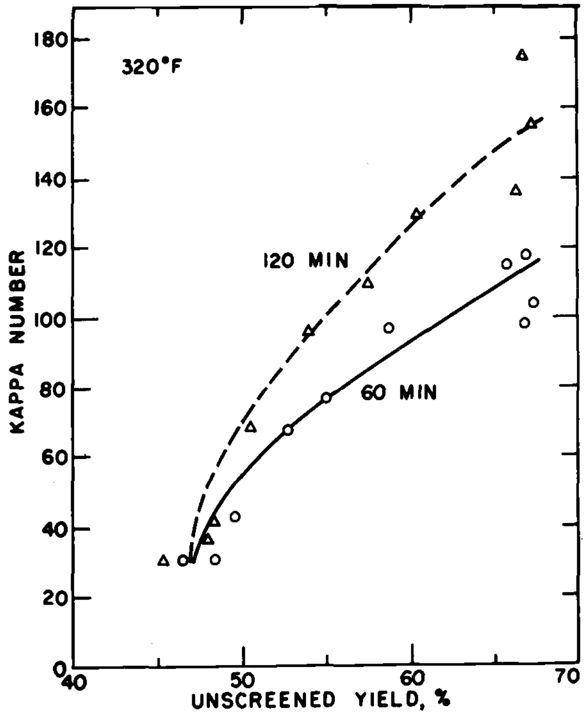

Figure 6. Kappa numbers as functions of total yield and cooking temperature.

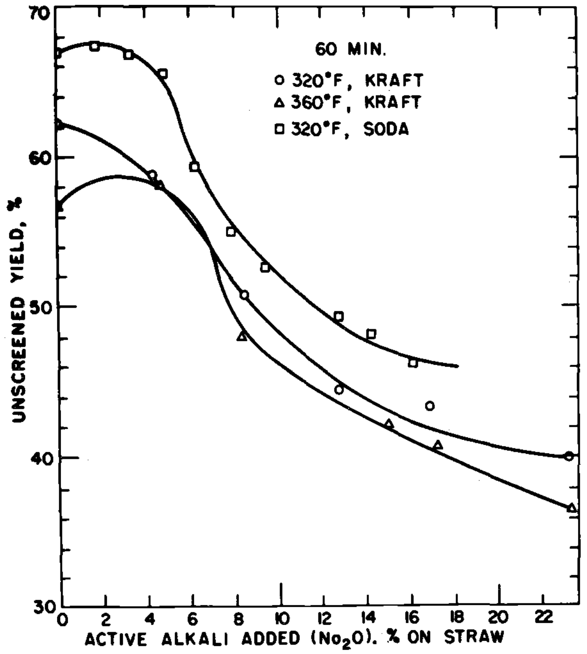

Figure 7. Comparison of unscreened yields of ryegrass pulped by soda and kraft processes.

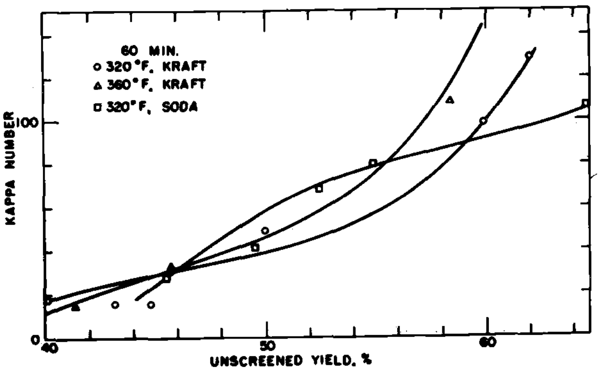

Figure 8. Kappa numbers and yields compared for ryegrass straw pulped by soda and kraft processes.

either process would be used in this yield range is debatable, because NSSC processes are more popular here. As before, cooking at 360 F produces pulps with higher Kappa numbers than cooking at 320 F, at equal pulp yield. Therefore, in kraft pulping of straw, as in soda pulping, cooking at the lower temperature would be desirable.

Pulping in Larger Digesters

The previous work was designed to make plain the proper pulping conditions for the soda and kraft processes, but pulp yields from the bombs were too small for full testing. Consequently, the next step was cooking in digesters that held one kilogram of dry straw (12-liter capacity). In general, results from the digesters are more reliable than those from the bombs.

Cooks in the digesters usually were run at 320 F for one hour at maximum temperature, after a 45-minute period to rise to temperature. As with the bomb cooks, these cooks were made with various amounts of active alkali to obtain different yields and pulps of different Kappa numbers. Comparing effects of the two types of digesters, the data can be summarized as follows:

At constant pulping time and amount of chemical added, the larger digester produced higher pulp yields.

At constant chemical addition and cooking time, the larger digester produced pulp with lower Kappa numbers.

At constant pulp yield and cooking time, the larger digester produced pulp with lower Kappa numbers.

These conclusions are valid for both the kraft and soda pulps.

Pulps with yields in the low semi-chemical range, with Kappa numbers below 50, can be produced easily in a short time in the large digester. Although the majority of the cooks were run for one hour at maximum temperature, later experiments indicated that even shorter cooking times were feasible. Thus, three cooks conducted for only 15 minutes at temperature, with the usual 45 minutes for rise to temperature, suggests that shorter cooking times are more desirable for straw. The relation of yield to Kappa number for these short cooks falls in line with those of the one-hour cooks. This reinforces our belief that short cooking times for straw are more desirable than longer cooking times.

Comparison of Soda and Kraft Pulps

A comparison of pulp properties for soda and kraft cooks, given in Table 1, is based on equal yields, which range from 60 to 45 percent. These comparisons are based on four 1-kilogram cooks each of kraft and soda, with different amounts of alkali in each instance, and on a freeness of 100 CSF rather than on normal freeness values. (The initial freenesses of the straw pulps are normally quite low, relative to wood pulp, typically from 100 to 200 ml Canadian Standard Freeness (CSF), so strengths at freenesses over 200 CSF are not usually available.)

At constant yields, Kappa numbers of the soda pulps are lower than those of the kraft pulps in the high-yield range, but higher in the low-yield range. Initial freeness of kraft pulp is considerably higher than soda pulp in the high-yield range, but is lower in the low-yield range. This is an obvious advantage for the high-yield kraft pulps. At all yields, kraft pulps make

Table 1. Comparison at Constant Yield of the Properties of Straw Pulps Made by the Kraft and Soda Processes.

Pulp property	Pulp with higher test value at	
	High yield (55-60%)	Normal yield (45-50%)
Kappa number	Kraft	Soda
Initial freeness	Kraft	Soda
Density, 100 CSF	Kraft	Kraft
Tensile, 100 CSF	Equal	Equal
Stretch, 100 CSF	Kraft	Equal
Mullen, 100 CSF	Kraft	Equal
Tear, 100 CSF	Soda	Equal
Fold, 100 CSF	Equal	Soda
Brightness	Equal	Equal

denser paper than do soda pulps, but generally the strengths of the kraft and soda pulps are substantially equal over the range of yields encountered in this work. Tearing strength of soda pulp is significantly higher than that of kraft pulps, particularly in the medium and high-yield ranges.

Thus, soda pulps in the normal-yield ranges seem comparable in strength properties to kraft pulps. Because Kappa numbers of the two types of pulps at constant yields are equal, kraft pulping of annual ryegrass straw offers no significant advantage over soda pulping. Odor of the kraft process is another factor detrimental to its use.

Table 2 presents average results of five soda cooks with yields ranging from 50 to 52 percent, a range that might be considered suitable for either unbleached or bleached usages. For comparison, strength values for other pulps at 200 CSF, the approximate freeness of the unbeaten straws, are included in this table. Straw pulps compare quite favorably with most pulps in those strength properties that relate to fiber bonding, such as tensile, stretch, burst, and folding endurance. Conversely, tearing strength is low compared to softwood pulps because of the short length of straw fibers, which was pointed out in our original article (2). Little dirt, nodal material, shives, or other debris are noticed in these unbleached pulps. The major drawback is the short length of fibers and the resulting low freeness of the unbeaten pulps. Blended with long-fibered pulps with higher freenesses, the slow-drainage characteristic may not be a limiting factor in utilization of straw pulps for improvement of formation and strength properties.

Summary of Laboratory Alkaline Pulping

We find that the kraft process offers no major advantage in delignification or pulp quality compared to the soda process for pulping annual ryegrass straw. The amount of screenings is low at yields below 55 percent, and the pulp is generally clean and free of shives and nodal material. Cooking for only 15 minutes at maximum temperature yields high-quality pulps by the soda process, and short cooks in modern continuous digesters seem feasible. Yields are in the range of full-chemical wood pulps, and the amounts of pulping chemicals needed are reasonable. Unbleached soda straw pulps might find use in linerboard, where a short fiber is

Table 2. The Properties of Unbleached Soda Pulp at 50 Percent Yield Compared to the Properties of Other Pulps[a], All at 200 CSF.

Pulp type	Yield	Kappa number	Brightness	Initial CSF	Density	Breaking length	Mullen	Tear	Fold
	%		%	*Ml*	*G/cc*	*Meters*	M^2/cm^2	Dm^2	
Annual ryegrass, Soda pulp	51.5 0.8	25.1 2.0	29.6 1.5	184 46	0.57 0.16	9,400 1,200	50 8	63 4	1,100 100
Douglas fir thinnings, Unbleached kraft pulp[b]	49.0 2.5			700	0.74 0.04	10,800 900	74 10	112 20	1,200 230
Commercial kraft pulp, Douglas fir[b]	49			700	0.82	9,000	68	110	1,100
Kraft bigleaf maple pulp, cook 5[c]	51.2	13.6	39	700	0.86	11,000	75	75	2,400
Bleached western hardwood sulfite[d]			93		0.76	5,700	37	70	80

[a] All pulps cooked in 1-kg digester. Averages are on top lines, standard deviations are on bottom lines.

[b] Bublitz, W. J., Tappi 54(6):928. 1971.

[c] Farr, T. D., "THe Pulping Characteristics of Bigleaf Maple (*Acer macrophyllum* Pursh)." Oregon State University. p. 44. MS Thesis, School of Forestry. 1970.

[d] Bublitz, W. J. and T. D. Farr, Tappi 54(10):1716 1971.

desirable to improve the smoothness and thereby the printability of the board, or to improve its tensile and bursting strengths. As our first article shows (2), blends of straw pulps with softwood kraft pulps can improve the tensile and bursting strengths of a long-fibered pulp such as Douglas fir.

Bleaching of Soda Pulps

Straw pulps have been used for many years in fine or bond papers, primarily because of their short fibers, which can improve the formation and optical characteristics of these papers. White pulp is used in these grades, and the following section describes our efforts to bleach annual ryegrass soda pulp.

A series of bleaching experiments was performed in the laboratory to determine the optimum bleaching sequence for straw pulps of this type. Multi-stage bleaching studies indicated that these pulps can be bleached readily with conventional commercial bleaching chemicals (7). Not surprisingly, the Kappa number of the unbleached straw pulp strongly influenced the bleaching reactions. If the unbleached pulp had a Kappa number greater than 30, it was difficult and costly to bleach, which is analogous to the situation for wood pulps.

The laboratory bleaching data will be summarized only. Annual ryegrass soda pulp, produced with an unbleached Kappa number of 20 to 30, can be bleached readily with minimal quantities of chlorine and caustic compounds to a brightness between 85 and 90 percent, using conventional bleaching sequences. The pulp was free of shives and unbleached fiber bundles after final bleaching.

Bleaching included various sequences of four steps: Chlorination (C), alkaline extraction (E), hypochlorite (H), and chlorine dioxide (D). Three-stage bleaches, with sequences of CEH, CED, and DCE, produced pulps with brightnesses from 84 to 86 percent (Elrepho). A typical sequence would be 4 percent chlorine, 2 percent caustic, and 2.5 percent hypochlorite to a brightness of 86 percent. Four- and five-stage bleaching experiments indicated that brightnesses of 90 percent could be achieved with a reasonable consumption of chlorine chemicals. For example, a CEHD sequence of 4 percent chlorine, 2 percent caustic, 2.5 percent hypochlorite, and 0.5 percent chlorine dioxide gave a brightness of 90 percent. A common factor in these experiments was the requirement that adequate chlorine (or chlorine dioxide) be added in the first stage to assure the proper amount of lignin degradation, which is measured by the Kappa number after the CE state. If it was above 6 at this point, it indicated insufficient chlorination in the first stage, and predicted difficult bleaching in succeeding stages. With these restrictions, however, soda ryegrass pulp can be bleached easily to brightnesses of 85 percent or higher.

PILOT PLANT BLEACHING AND PAPERMAKING

We made one pilot plant trial to demonstrate the feasibility of producing a fine or bond paper from bleached ryegrass straw. This work was done at the Central Research Division Laboratory of Crown Zellerbach Corporation in Camas, Washington, between November 29 and December 4, 1972. Because of limitations in equipment, part of the work was done at the Forest Research Laboratory and the remainder at the laboratory in Camas.

Preparation of Unbleached Pulp

The pulping was done at the Forest Research Laboratory in Corvallis. Our large rotary digester was used for these trials, with 20 kilograms (oven-dry basis) of cubed straw per batch. The pulping data are given in Table 3.

A new technique was attempted at this time. We mentioned earlier the difficulty of handling straw pulp because of the short fiber length and resultant low freeness and slow drainage. After a cook, the defibered pulp normally has a freeness below 250 CSF, even though it is unbeaten at this stage, and this leads to difficulty in washing and draining the pulp.

Preliminary experiments had indicated that it was not necessary to defiberize the pulp completely in the washing operation following the pulping to produce a bleachable pulp. The soda black liquor apparently could be removed adequately, even though the pulp was still in a coarse, grasslike form, and disintegration of the bundles into the final fiber form could be delayed until a later stage of the pulp processing.

Thus, for the pulp to be bleached at Camas, we removed the pulp from the digester and washed it in a suction box without disintegrating the pulp. This considerably expedited washing and draining, and, as Table 3 shows, the initial freeness of these pulps averaged about 470 CSF. Laboratory tests showed that this undisintegrated pulp could be bleached by regular bleaching sequences, which indicated adequate removal of black liquor from the pulp.

We were not able to determine accurately the yields of these cooks, but based on the Kappa-number–total-yield relation obtained earlier, we estimated it to be from 50 to 53 percent of the original straw. By comparison, it is usually necessary to cook wood to a yield well below 50 percent if the pulp is to be bleached. This illustrates one of the potential advantages of pulping straw compared to wood.

Table 3. Data for Preparation of Unbleached Pulp.

CONDITIONS

Rotary digester in FRL
Digester charge: 20 kg. O.D. cubed straw
Chemical: 16% NaOH as Na_2O
Liquor:Straw::4:1
Time to temperature: as soon as possible
Time at temperature: 1 hour
Temperature: 320°F

	UNBLEACHED PROPERTIES	
Cook No.	Kappa No.	Initial CSF
1[a]	23.2	480
2	17.6	480
3	29.9	470
4	20.1	490
5	20.6	420
6	28.2	480

[a] Cook 1 required 6 minutes in Valley beater to reach 160 CSF.

Bleaching of Pulp

Limitations in equipment in the Crown Zellerbach Laboratory made chlorine dioxide necessary in the first stage of bleaching instead of chlorine. Thus, before the trials at Camas, we investigated bleaching in DED and DEH sequences in laboratory trials at Corvallis. We were unable to obtain the same degree of bleaching with chlorine dioxide in the first stage as with chlorine, but we developed a four-stage bleaching sequence that gave 85-86 percent brightness (Table 4). A total of 9 percent available chlorine and 2 percent caustic thus was recommended by the Forest Research Laboratory for the pilot plant bleaching trials.

The first bleaching stage at Camas was conducted in a glass-lined Pfaudler kettle with a capacity of 200 pounds of pulp, but we had only 90 pounds of dry pulp for this stage. The required amount of chlorine dioxide was added and was exhausted quickly. The pulp was dumped into a box with a false bottom to remove the waste bleach liquor and wash the pulp.

Unfortunately, our plan to preserve high freeness failed in this stage, because the vigorous agitation and high temperature inside the kettle during the bleaching apparently broke the straw pulp down to a fibrous form. Before the first stage of bleaching, the pulp had a freeness of over 300 CSF, but was down to 110-150 CSF afterwards. This indicated complete defibration of the straw bundles. Thus, washing and draining of the semibleached pulp were time consuming in subsequent stages, and our goal of maintaining an undefibered straw up to the paper machine was destroyed.

The caustic-extraction stage was conducted in a stainless steel ribbon mixer in contrast to the glass-lined kettle used for the first stage. No problems were encountered in the second stage, with the exception again of slow drainage time. For the third stage, we used chlorine dioxide instead of hypochlorite as had been recommended originally. The permanganate number of the pulp after the CE stage was only 2.2, which is a rather low value, and a minimal amount of chlorine dioxide seemed to be required in the third stage to reach a brightness of 85 percent. A total of 2.6 percent available chlorine in the form of chlorine dioxide was added in the third stage, but brightness of the bleached pulp was only 78 percent and there were many unbleached shives present at the end.

A fourth stage was necessary, adding 2.4 percent chlorine dioxide as available chlorine, giving a final brightness of 83 percent, which was close to our goal of 85 percent. Rather severe losses of fiber were encountered in the handling between bleaching stages because of the slow drainage, and we decided against further bleaching to raise the brightness to 85 percent or above. The fourth stage of bleaching, however, did completely bleach the pulp and remove all the dark fiber bundles and shives. The final bleached pulp was extremely clean in this respect.

Loss in yield was high, and we estimated that we had only about 60 pounds of bleached pulp out of the original 90 pounds with which we started. This should not be taken, however, as indicative of the true loss of fiber in the bleaching sequence. Laboratory studies have indicated that the chemical loss in a normal bleaching sequence would be about 10 percent of the unbleached pulp, which is fairly normal.

Although we were unsuccessful in maintaining the desired high freeness of the pulp during the bleaching stages, we believe that this was a result of limitations in equipment at the Crown Zellerbach Laboratory. If straw pulping were to be scaled up to a commercial level, bleaching equipment might be redesigned so that agitation would be more gentle and the straw bundles not be defibered into individual fibers. In this way, high freeness could be maintained and interstage washing would be accomplished more readily. This is a matter of equipment design and should offer no major obstacle to bleaching and handling of straw pulp.

Table 4. Data for Bleaching Unbleached Straw Pulp.

Stage	Chemical	Chemical added[a]	Straw input	Straw output	Consistency	pH at end	Temperature	Bleach time	Kappa number	Brightness in	Brightness out
		%	*Lb*	*Lb*	%		*Deg F*	*Hr:Min*		%	%
1	ClO_2	1.5	92	82	12	4.2	160	3:00	15	34	67
	As Cl_2	3.9	--	--	--	--	--	--	--	--	--
2	NaOH	2.0	82	70	12	11.2	160	1:00	2.2	67	58
3	ClO_2	1.0	70	--	12	2.5	160	1:30	--	58	78
	As Cl_2	2.6	--	--	--	--	--	--	--	--	--
4	ClO_2	0.9	--	61	12	2.8	160	1:30	--	78	83
	As Cl_2	2.4	--	--	--	--	--	--	--	--	--

Conditions Recommended by FRL to Final Brightness of 85%.

Stage	Chemical[a]	Consistency	Temperature
	%	%	*Deg. F*
Chlorine dioxide	6.0 as Cl_2	6	100
Alkaline extraction	2.0 as NaOH	6	160
Hypochlorite	2.5 as Cl_2	6	160
Chlorine dioxide	0.5 as Cl_2	6	160

[a] Percentage chemical added, based on straw.

Papermaking Conditions

The bond paper was made on a pilot plant Fourdrinier machine at the Camas laboratories, which produces a sheet about 24 inches wide at a maximum speed of slightly over 100 feet a minute. Our goal in this trial was to simulate a No. 1 sulfite bond paper that is used widely in business and industry today. We made a control paper also, a reference against which the straw paper could be compared, from a blend of 50 percent kraft softwood and 50 percent kraft hardwood pulp. The softwood pulp gives the paper its strength characteristics, and the hardwood pulp improves formation and opacity of the sheet. This is a fairly common blend of fibers for some kraft bonds on the market (even though called "sulfite" bonds).

The clay filler, the rosin size, and the surface sizing formulae used were suggested by Crown Zellerbach personnel as being typical of commercial bond paper production. These additives were used in the same proportions for the control and straw paper trials.

Machine conditions are given in Table 5. The major difference between the control and test runs was in the freeness of the pulps. The control pulp blend was refined to a freeness of about 350 CSF, and the kraft softwood pulp was refined separately to 450 CSF before blending with the straw pulp. The goal for this procedure was to obtain the same head box freeness in each instance, which did not happen. The straw-softwood blend was substantially lower in freeness than the control blend, but the operators nevertheless were able to run the machine at the same speed, 85 feet a minute, for both trials. No difficulty was encountered with either pulp regarding drainage, foam, press roll sticking, drier sticking, or drying in general.

As usual with short runs on pilot plant machines, to establish ideal running conditions in the short time available was difficult, and moisture contents and finishes of the papers were not optimum. Our goal was 6 percent moisture in the sheet, but this ranged from 3-4 percent to as high as 9 percent during the trials. Similarly, there was a considerable amount of cockle in both sheets during the trials, most of which could have been eliminated if the operators had had enough time to adjust the operation of the machine.

Paper Testing

Test results are given in Table 6 and are compared with average values for eight commercial sulfite bonds that had been tested at the Forest Research Laboratory. We were not successful in matching the average properties of the eight commercial bonds in all respects, because of the shortness of the trials. The biggest difference was in ash content, with the eight commercial bonds averaging 7.7 percent ash, compared to only 4.2 and 5.2 percent for the control and straw paper. This is reflected in the higher opacities of these commercial bonds, which average 88.6 percent, compared to 81-84 percent for the test papers. Had we added more filler or been able to retain more filler in the sheet, we would have been able to raise the ash content and thereby improve the opacity.

Similarly, average brightness of the commercial bonds was higher than those of the two trial papers, but this could be corrected in future trials. The S-coefficient, which determines the opacity of paper, is substantially lower for the two test papers, and this also relates to the ash or filler content of the respective papers. Note that the scattering coefficient of the pure straw pulp, 510 square centimeters per gram, is nearly equivalent to the S-coefficients of the commercial bonds. This is significant because the high S-coefficients of the bonds are caused

Table 5. Machine Run Conditions for Experimental Bond Paper.

	Paper	
Item	Control	Straw
Furnish		
Weyerhaueser regular kraft, %	50	50
Crown Zellerbach bleached alder, %	50	--
Annual ryegrass bleached straw, %	--	50
Batch size, *Lb*	200	120
Refined to *CSF*	334-350	450[a]
Additives		
Pexol rosin size, %	0.75	0.75
Hi white clay, %	4.0	4.0
Hi opaque clay, %	4.0	4.0
Alum to *pH*	5.1	5.5
Headbox freeness, *CSF*	240	155
Headbox consistency, %	0.63	0.64
Wire speed, *Ft/min*	85	85
First press loading, *psi*	20	20
Second press loading, *psi*	40	40
Sizing formulation, % (both control and straw paper)	Penford Gum 260	84
	Scripset 500	2.5
	Tipure LW	9.2
	Polyglycol 4000	0.2
	Urea formaldehyde 8% solids	4.0
First section driers, *psi*	8	8
Second section driers, *psi*	12	8
Calender stack	1 nip	1,000 psi gage

[a] Kraft pulp was refined to 450 CSF in beater, then unbeaten straw pulp (about 180 CSF) was blended with it.

mainly by the fillers and not the fibers. Consequently, the straw pulp has good opacity, in spite of its low freeness and high sheet density, and this is a rather unusual characteristic.

In general, strength properties of the two test papers are superior to those of the sulfite bonds in such categories as tensile, stretch, tear, fold, and bursting strengths. This superiority is caused by the choice of pulps used in our trials, and can be modified by choosing other pulps. Nevertheless, it shows that straw pulp, blended with the proper softwood pulp, can make a bond sheet that is comparable in all strength characteristics to commercial bond paper.

The straw paper has a higher ash content and thereby better opacity, as well as a higher scattering coefficient, than the control paper. Brightnesses of the two sheets are about the same, but formation and smoothness of the straw paper are superior to those of the control papers. This may be attributable in part to the lower freeness of the straw pulp and may reflect

Table 6. Testing Results for Bond Papers.

	Average 8 sulfite bonds	Control paper	Straw paper
Basis weight, *Lb*[a]	19.8	19.0	21.4
Density, *g/cc*	0.74	0.74	0.82
Caliper, *mils*	3.98	3.80	3.86
Moisture, %	5.8	6.1	6.4
Cobb size test, *g*	24-29	24-27	35-37
Hot water extract, *pH*	5.1	5.0	4.7
Dirt, *ppm*	0.7-0.9	0.5-0.7	0.2-0.8
Sheffield smoothness	---	237-249	183-217
Ash content, %	7.7	4.2	5.2
Wax pick test, *pick*	18	18	18-20
Wax pick test, *rupture*	20	20	20-23
Formation	---	0.45	0.35
Porosity, *sec/100 cc*	21	220	490
Brightness, %	88.6	82,2	81.9
Printing opacity, %	88.6	81.0	84.4
S-coefficient, cm^2/gm	541	379	388 (510)[b]

	Direction		Direction		Direction	
	Machine	Cross	Machine	Cross	Machine	Cross
Tensile strength, *meters*	5,880	3,360	8,920	3,390	7,470	2,730
Stretch, %	2.1	4.4	2.2	4.0	2.7	4.3
Tear factor, dm^2	78	79	90	105	94	114
Fold	78	56	211	57	317	61
Burst factor, m^2/cm^2	24		32		36	
Aging stability, %	57		74		93	

[a] Weight of 500 sheets, size 17 by 22 inches.
[b] S-coefficient of pure straw pulp.

its finer fiber structure. It is reflected also in the lower porosity and higher density of the straw paper. Tensile strength of the straw paper is slightly below that of the control, but the tear factor is better and the burst or Mullen strength is also superior. Overall, the straw paper is at least as strong as the control paper, and in terms of certain aesthetic values, it is superior. Note particularly the aging stability of 93 percent for straw compared to 74 percent for the control paper. This is a test of the retention of folding endurance after a period of oven-aging, and indicates that the straw paper would have better shelf life than the control.

Summary

We conclude that straw pulp compares favorably with a bleached hardwood pulp for use in a No. 1 sulfite bond paper. The straw paper is overall as strong as the hardwood paper, and apparently can be produced under the same machine conditions as the hardwood pulp paper. Smoothness and general optical characteristics of the straw paper are superior. Thus, if the problems of pulping and bleaching can be solved, a bleached straw pulp from annual ryegrass straw apparently could be a satisfactory substitute for hardwood pulps in the manufacture of fine paper.

SEMICHEMICAL PULP FOR CORRUGATING MEDIUM

Introduction

Another of the major end uses of straw pulp is corrugating medium, the fluted core of corrugated boxes that furnishes stiffness and rigidity. This was the major use for straw pulp in the United States before World War II, rather than fine papers. Only with the advent of the NSSC process for producing hardwood corrugating medium did straw lose its place in this particular market.

Laboratory Work

Our work was on the NSSC and soda processes for producing corrugating medium, and the results are given in Figure 9. The pulping conditions were derived from past experience in producing NSSC corrugating medium pulp from west coast hardwoods. In general, pulping conditions that are suitable for hardwood also work for straw pulp, although less chemical and shorter cooking times are necessary for straw pulp than for hardwood pulp. Concora strengths in the 60 to 65 psi range, at freenesses between 100 and 200 CSF, were obtained easily with the straw pulp, and the yield-strength relation was comparable to that of the west coast hardwoods. Based on this laboratory work, we decided to make a larger scale trial of corrugating medium pulp at the Crown Zellerbach laboratory in Camas.

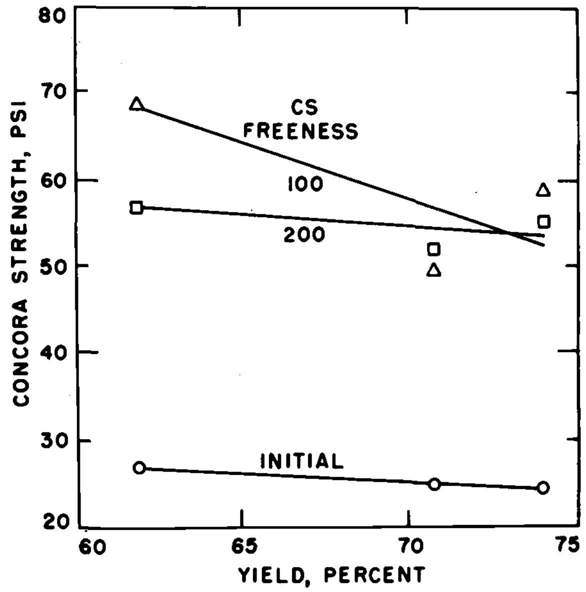

Figure 9. Relations of yields and Concora strength of ryegrass straw pulped by NSSC process.

First Pilot Plant Trial of Corrugating Medium

Pulping and Refining

The first trial on this project was conducted at the Central Research Division Laboratories in Camas, Washington, May 8 to 11, 1972. Straw cubes were pulped in a 100-cubic-foot rotary spherical digester, using a neutral sulfite pulping solution.

Although there was not a great deal of difference in our laboratory work between results of the soda and neutral sulfite pulping processes, we decided to use the latter in our pilot plant trials. The soda process pulps straw so rapidly that it was difficult to control the degree of pulping and the yield. Even 15- to 20-minute cooks frequently would lower the yield of soda pulps below the target value, but the neutral sulfite process seemed to be milder and thus allowed better control of the pulping operation.

The pulping conditions at Camas are given in Table 7 for the first and second trials of corrugating medium. Our original goal was to pulp for 15 minutes at maximum temperature and pressure, but because of limitations in equipment, the digester was at this temperature for nearly an hour. We were unable to blow the entire contents of the digester into a blow pit, as normally would be done in production, but instead had to drain off the liquor under pressure from the digester. This required passing the liquor through a screen in the blow line of the digester, and the screen quickly became plugged with straw fiber, which greatly extended the blowdown time. To establish yields accurately was difficult, but based on the paper machine production we estimated that the yield was about 65 percent, somewhat lower than our target value. This could be caused in part by the longer cooking time and in part by loss of fiber during transfer operations.

The pulp was disintegrated in a Bauer Model 411 double-disk refiner, where freeness dropped from about 300 CSF to about 150 CSF. About 11 horsepower-days per ton of power were consumed in this refining step, which is about half the consumption of power that would be necessary for hardwood chips in the same yield range. With the exception of the blowdown process, no problems were encountered in pulping, and we concluded that straw could be pulped satisfactorily by the neutral sulfite process.

Paper Machine Trial

The corrugating medium was produced on the 24-inch-wide pilot plant Fourdrinier machine in Camas. Furnish for the straw paper trial was a blend of 80 percent of the NSSC straw pulp and 20 percent of old corrugated box clippings by dry weight. The clippings were obtained from Western Kraft Corporation in Albany, Oregon. They were soaked in water and disintegrated in a beater, and served as a source of long fiber for the corrugating medium. This is a common practice in the corrugated medium industry, with some mills using as much as 50 percent of these clippings in their furnish. They represent a low-cost source of long fiber, which improves the runnability of the medium on the corrugator. The machine run conditions are given in Table 7.

A control run, utilizing repulped corrugating medium, was made to produce a material from commercial fiber on the same paper machine as the straw paper. The control run was made first, followed by the test run. There were problems in establishing the proper basis weight, caliper, and moisture content of the papers because of limited stock supply and short running time. As a result, the control medium was lighter than desired, and the test or straw medium was heavier. No difficulties were encountered with either furnish so far as foam,

Table 7. Pulping and Papermaking Conditions for Corrugating Medium Trials.

Condition	Trial 1		Trial 2
	PULPING TRIAL CONDITIONS		
Straw charge, *lb*[a]	815		794
Liquor charge	4:1::liquor:straw		4:1::liquor:straw
Chemical charge			
Na_2SO_3, % *on straw*	6		6
Na_2CO_3, % *on straw*	4		4
Preheat liquor, *deg F*	180		180
Transfer to digester, *min*	5		5
Bring to temperature, *deg F*	315		315
Hold at temperature, *min*	15		15
Blow time, *hours*	1.0		0.5
Blow liquor, *pH*	7.5		7.4
Target yield, %	70-72		70-72
Actual yield, %	65		65
	REFINING CONDITIONS		
Plate setting, *in.*	0.19		0.22
Refiner current, *amp*	35		30
Pulp freeness, *CSF*	175-200		350
Eye water, *gpm*	4.5		4.5
Flush, *gpm*	30		30
	PAPERMAKING CONDITIONS		
	Control paper	Straw paper	Straw paper
Furnish	Re-pulped corrugating medium	80% straw 20% clippings	80% straw 20% clippings
Refining power, *amp*	7	5	0-2
Stock chest freeness, *CSF*	380	130	150
Headbox freeness, *CSF*	250	130	140
Headbox consistency, %	1.0	1.0	1.1
Wire speed, *ft per min*	50-60	50-60	55
Wire type	(all trials) 185 x 69 triple chain bronze wire		
Drier steam pressures, *psi*	30-60	30-60	30-60
Caliper, target, *mils*	9	9	9
Caliper, actual, *mils*	9-10	10-11	9-10
Basis weight, target[b]	26	26	26
Basis weight, actual[b]	22	28-29	25-26.5
Moisture content, %	3-7	3-7	5-7

[a] Oven-dry basis.

[b] Basis weight, pounds per 1,000 square feet.

drainage, couching, press roll sticking, or drying were concerned, and both trials were considered satisfactory in this respect.

Corrugating Runnability Trial and Test Results

The rolls of control and straw paper were re-wound, trimmed to 12 inches wide, and sent to the Institute of Paper Chemistry in Appleton, Wisconsin, where runnability trials were performed on June 19, 1972. The runnability machine is essentially a full-scale corrugator, except for the width. It can handle a web only 12 to 15 inches wide, in contrast to commercial production machines, which can handle rolls of paper from 60 to 80 inches wide. Otherwise, the dimensions of the machine are identical to a commercial corrugator.

The paper is steamed before going into the corrugating nip. This operation heats the web and introduces moisture, thus plasticizing and making it more easily formed into the corrugating medium. The corrugating nip resembles a set of gears, which shapes the medium into the corrugated form. In the runnability test, the machine is started at a speed of 200 feet per minute, with minimum tension on the paper web going into the nip. The speed is increased sequentially, and if the process of corrugating and laminating is running satisfactorily at 600 feet per minute, the tension on the web is increased stepwise to a total of 2 pounds per lineal inch of web width. If no breaks occur at maximum web tension, the trial is considered successful. During this process, the medium is shaped into the corrugated form, adhesive is applied to the tips of the flutes, and the medium is laminated to a web of kraft linerboard to give a single-faced corrugated board. This is similar to commercial boxboard except that it has only one face of linerboard rather than the normal two faces of linerboard, with one laminated to each side of the corrugated medium.

The control paper, made from repulped corrugating medium, ran quite well up to 400 feet per minute, but above this speed it could not pick up enough adhesive. This was attributed to its low basis weight and caliper, which prevented good contact with the adhesive applicator roll. This was a minor problem.

The straw paper ran very well through these trials and no breaks were encountered. The flutes of the corrugating medium were well formed and stiff, and showed no evidence of cracking. The operators commented that everything appeared satisfactory and that similar materials should run well on commercial full-width corrugating equipment. The straw corrugating medium thus passed the runnability test satisfactorily.

Test results are given in Table 8, and compared with typical results of commercial corrugating medium. The data indicate that the straw medium is low in flat crush resistance,

Table 8. Test Results of Corrugated Medium.

Measurement	Commercial medium	Trial 1		Trial 2, Straw
		Control	Straw	
Tests on medium only				
Basis weight, *lb/1,000* ft^2	26	22	29	26
Modified ring compression, *lb/inch*	12-13	10.6	12.6	12.7-13.6
Concora strength, *psi*	60-65	60-61	61-65	52-56
Tests on single-faced board				
Ring compression, *lb/20 inch*	500-600	480	620	540-590
Flat crush, *psi*	33-35	32	30-31	23-27

although not seriously so. In other tests, such as ring compression, it seems to be satisfactory. Note that test values given for the straw medium are adjusted to a 26-pound basis weight, which is the standard for the industry.

Second Corrugating Medium Trial

Pulping and Refining

Because of the low flat-crush resistance of the first trial run of straw corrugating medium, we decided to make another trial to improve mainly this aspect of the paper. Goals of the second trial were to produce pulp at a higher yield, preferably 70 percent or higher, keep freeness of the pulp higher, use a better grade of clippings, and increase flat crush strength of the corrugating medium. We thought that a better grade of clippings, for example, might improve the crush resistance of the medium. This trial was conducted again at the Crown Zellerbach Corporation laboratories in Camas, on August 3 and 4, 1972, and the pulping conditions were essentially the same as those in the first trial (Table 7). The major difference between the two pulping trials was the shorter blow time, 30 minutes, compared to 1¼ hours in the first trial. The shorter blow time was accomplished by venting steam through the top relief line rather than blowing waste liquor, because the latter technique tended to plug the blow screen with straw fibers. The maximum temperature was somewhat lower, and the shorter cook time should have raised the yield of the cook. We could not detect any improvement in the yield of this second trial, so we apparently produced about the same grade of pulp.

The refining conditions were less severe, in an attempt to maintain a higher freeness and faster machine drainage. The corrugated box clippings used in the furnish were a premium grade of material, again donated by Western Kraft Corporation for the purpose. There was, however, a certain amount of material that was not disintegrated easily and showed up on the final product as lumps of paper.

Papermaking Trial

Conditions for the second machine run, given in Table 7, were similar to conditions of the first machine trial. During the trial, a paper sample was checked for Concora crush strength. It tested only about 50 psi, which was lower than the target value, so a slight amount of additional refining was given to the stock to improve the sheet density and thereby raise the Concora strength. Tests showed that the strength was raised to 55-60 psi, which seemed adequate at the time.

Corrugating Runnability Trial and Test Results

Rolls of this material were sent to the Institute of Paper Chemistry for runnability trials and product testing. Runnability of the various samples submitted was quite acceptable, as was true in the first trial, but flat crush and Concora strengths were somewhat lower (Table 7). Lack of funds has prevented further trials to optimize the stiffness and crush resistance of straw corrugating medium.

Conclusions

Annual ryegrass can be pulped by the neutral sulfite process to produce semi-chemical pulps suitable for corrugating medium. With normal amounts of long-fibered pulp (boxboard clippings), the papers are adequately strong for running on today's corrugating machines at top speeds and maximum web tensions. Flat crush and Concora strengths are somewhat lower than normal, but we anticipate that these properties could be increased to meet industry specifications with further research. The ring compression tests and others seem to be satisfactory. Corrugating medium pulp quality is overall a function of pulp yield, and the straw pulps were in the same range of yields as wood pulps, for equivalent degrees of corrugating-medium quality. Further trials are necessary to optimize the process and produce a competitive corrugating medium from straw.

MISCELLANEOUS EXPERIMENTS

Bleaching of Ground Straw

A mechanically prepared straw pulp, similar in nature to refiner groundwood, was prepared by treating annual ryegrass in boiling water for 5 minutes, followed by grinding in the PFI mill in the laboratory. The conditions for grinding are given in Table 9. Freeness of the straw pulp was between 70 and 80 CSF, close to that of refiner groundwood.

The ground straw was bleached with various chemicals commonly used for groundwood, such as zinc hydrosulfite and the various peroxides. Very little gain in brightness was achieved with these chemicals, the maximum consisting of seven points gain in brightness with 2 percent hydrogen peroxide. As the unbleached brightness was only 37, these did not appear feasible techniques for preparing a bleached ground straw pulp that would be a suitable replacement for refiner groundwood. In addition, the handsheets were weak and brittle, and did not seem to have the strength of normal groundwood. Work on this phase of straw processing has not been pursued further.

Table 9. Preparation and Bleaching of Ground Straw.

Grinding of ground straw					
Consistency	10.0%				
Pulp charge	22.5 g				
Beating time	18,000 revolutions				
Bleaching of ground straw					
	1% ZnS_2O_4	2% ZnS_2O_4	1% H_2O_2 1% Na_2O_2	2% H_2O_2	2% Na_2O_2
Pulp charge, *g*	22.5	22.5	22.5	22.5	22.5
Bleaching consistency, %	10.0	10.0	10.0	10.0	10.0
Bleaching temperature, *deg C*	50	50	60	60	60
Bleaching time, *hr*	1.0	1.0	4.0	4.0	4.0
Initial *pH*	---	---	10.35	10.25	10.40
Adjusted *pH*	5.5	5.5	---	---	---
Final *pH*	---	---	7.9	7.6	7.8
Brightness, top	4.21	41.8	41.7	44.0	38.1
Brightness, bottom	40.5	38.4	40.8	41.8	37.6

Other Types of Straw Pulps

Although annual ryegrass is the single species grown in greatest amounts in the Willamette Valley, there are substantial tonnages of straws from other grass species. Not all of these species need to be burned, and some were investigated to see whether they had similar pulp properties.

Properties of the various grass straw pulps are compared in Figure 10 with annual ryegrass pulp. The alta fescue straw pulp is somewhat superior to pulp from annual ryegrass in the three most important strength properties, tensile, bursting, and tearing strength. By contrast, the bluegrass straw produces pulp much weaker than pulp from either ryegrass or fescue, thus eliminating bluegrass straw as a candidate for papermaking. Note that although fescue and ryegrass pulps are nearly as strong as Douglas fir pulp in tensile and bursting strengths, all the straw pulps are deficient in tearing strength, compared to Douglas fir pulp. This graph suggests, however, that grass straw pulps overall are not as weak as has been commonly assumed.

DISCUSSION

Recapitulating the criticisms of straw pulping given earlier, we offer the following comments:

Low pulp yields relative to wood. We think that this is not true, at least for annual ryegrass straw. Soda pulps with yields well over 50 percent have been produced that are nearly completely defibered with almost zero screenings. Wood pulps produced in this yield range probably would have to be defibered mechanically if the rejects are to be held to a reasonable level. Similarly, the yields of bleached straw pulp seem to compare favorably with those of bleached wood pulp, although the evidence is not quite so conclusive.

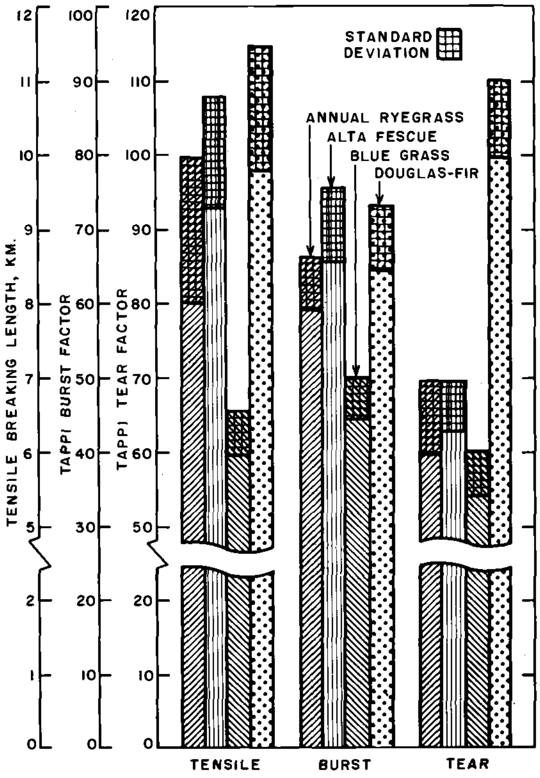

Figure 10. Strength properties of straw pulps and Douglas fir pulp compared.

The high bulk of straw, with its attendant difficulties. This is a difficult problem to solve, inasmuch as bulk is closely interrelated with such factors as the economics of storage, development of suitable machinery, and alternate uses for straw. We have shown, however, that cubed straw is technically feasible for pulping, and its properties suggest that it could be handled and stored in a manner similar to wood chips. Even greater efficiencies in digester packing are theoretically possible with cubed straw than with wood chips, although the economics of cubing straw may prove to be the major stumbling block to its acceptance.

Low freeness (slow drainage) of the straw pulp. We have shown in laboratory experiments that cooked straw need not be defibered until it is ready for papermaking, even for bleaching operations where good penetration of the individual fibers is essential for proper bleaching. Our one pilot plant trial failed in this respect, because the degree of agitation during bleaching was too severe to maintain the straw-like form, and the straw bundles were completely defibered. We hypothesize the development, at the time a straw pulp bleaching plant is to be constructed, of more gentle agitators for bleaching apparatus that will not defiber the straw bundles.

Weak paper properties. There is no question that straw pulps are deficient in tearing strength, relative to softwood pulps, but annual ryegrass pulp is not inferior in those strength properties that relate to fiber bonding, such as tensile, burst, and fold strengths. Ryegrass soda pulp forms strong, smooth sheets with excellent formation, and also has good opacity for its density. Overall, this pulp appears to be a worthy substitute for hardwood pulps that are used today in the paper industry.

High silica content of the straw. We have not fully investigated this problem, and do not have all the information needed. We have found that the silica content of the annual ryegrass straw is fairly low, about 1-1.2 percent silicon dioxide compared to 5-6 percent for rice straw, which is the most notorious material in this respect. For corrugating medium, the NSSC process should remove little silica from the straw, because the alkalinity is low (pH 7-9), in contrast to the strong alkalinity of the soda and draft processes (pH 12-14). Hence, recovery of the NSSC liquor may not be hampered by presence of silica in the liquor.

Recovery of either soda or kraft black liquor from ryegrass straw pulping definitely would be affected by silica in the liquor. Efforts are being made at various mills around the world, in conjunction with equipment suppliers, to cope with this general problem, however, and we anticipate that significant advances soon will be made in the technology of removing silica from black liquors. One mill in India has reported on a process for silica removal by treating the black liquor with lime to precipitate calcium silicate ($CaSiO_3$), which can be used as a paper filler. Although this process may not be universally applicable, it does illustrate some of the effort that is being expended to solve this problem.

Briefly, the problems of straw handling and pulping are not insurmountable. Other problems of even greater technical complexity have been solved by the paper industry with relation to wood pulping, and we anticipate that the problems of straw pulping and papermaking would be equally amenable to solution. There must be an economic incentive for the industry to tackle these problems, however, and incentive for straw pulping may arise in the near future from a growing shortage of wood fiber for papermaking. When wood becomes costly enough, straw may well be considered as an alternate source of fiber.

SUMMARY

An intensive study has been made of the pulping characteristics of annual ryegrass straw (*Lolium multiflorum* Lam.), a residue from production of grass seed in the Willamette Valley of Oregon. This straw can be pulped readily by conventional alkaline pulping processes, and yields of straw pulps are equivalent to those of wood pulps. Less than normal quantities of chemicals are needed for pulping, and pulping conditions are milder than for pulping wood. The unbleached straw pulps are clean and free from screening rejects, knots, and dirt that are found commonly in wood pulps. Paper made from straw pulps is smooth and well formed, and has tensile, bursting, and folding strengths essentially equal to those of softwood pulps. Tearing strengths of the straw pulps are lower than those of wood pulps, because the straw pulps have shorter fibers. These short fibers cause slower drainage, which impedes pulp and paper production on a commercial scale.

Soda pulp from ryegrass straw may be bleached readily, and this has been done on a semicommercial scale. The bleached pulp was made into a simulated No. 1 bond paper, and results indicate that straw pulp is equivalent or superior in quality to bleached hardwood pulp, which is blended commonly with softwood pulps in this type of product. Fine paper is a potential outlet for bleached straw pulps.

Ryegrass straw can be pulped by the neutral sulfite semichemical process (NSSC) to produce corrugating medium. A pilot plant trial was made to produce the paper, and it was tested for runnability. Runnability of the straw corrugating medium on the corrugator was excellent, and the straw medium is nearly on a par with commercial corrugating medium in most strength properties. It is slightly deficient in flat crush resistance.

Other grass straws were investigated, and alta fescue pulp is even stronger than ryegrass pulp. Fescue is of lesser importance because of the limited available supply.

Ryegrass straw has been pulped in chopped, cubed, and pelletted form. Packing efficiency in the digester is low using chopped straw, but using cubed or pelletted straw improves the efficiency by 200-250 percent, using wood chips as a basis for comparison. Pelletting damages the straw fiber so greatly that resultant pulp is weaker than pulp from either cubes or chopped straw. Cubing would seem to be a desirable way of densifying straw for handling, transportation, and storage, utilizing conventional equipment for wood chips. The economics of cubing may preclude this method of treatment.

Annual ryegrass straw makes high-quality bleached pulp suitable for fine papers, and when pulped by the NSSC process, it makes acceptable corrugating medium.

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