SULFATE PULPING OF LOGGING AND SAWMILL WASTES OF OLD-GROWTH DOUGLAS-FIR AND OF CERTAIN ASSOCIATED SPECIES

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SULFATE PULPING OF LOGGING AND SAWMILL WASTES OF OLD-GROWTH DOUGLAS-FIR AND OF CERTAIN ASSOCIATED SPECIES[1]

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Summary and Conclusions

Samples of Douglas-fir of a lower quality than desired for lumber were obtained from the vicinity of Oakridge, Oreg., and made into sulfate pulp at the Forest Products Laboratory. The samples included rough sound wood from suppressed trees, both old- and young-growth, and portions of old-growth wood infected with white pocket. Wood of equal density and chemical composition but with three stages of decay were pulped: (a) stained wood with incipient decay; (b) firm or intermediate rot; and (c) advanced rot.

Sulfate pulping tests were also made individually on sound mountain hemlock, noble fir, and lodgepole pine, which are associated with the Douglas-fir, and on a naturally occurring mixture of these species with Douglas-fir.

Douglas-fir and associated species were all pulped satisfactorily by the sulfate process with chemical requirements comparable with those of present mill practice. The pulps made from wood containing incipient, firm, and advanced rot were equal in yield and had a lower bleach requirement than pulps made from the sound wood.

The results obtained indicate that the following strength properties might be expected in strong sulfate pulps made from the various woods: (a) Pulp made from sound old-growth Douglas-fir wood might be slightly

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lower in bursting strength and significantly higher in tearing strength than southern pine sulfate pulp and probably could be expected to be used for purposes now served by southern pine pulp except where maximum bursting strength or a fine-fibered pulp are needed. (b) Sulfate pulps made from Douglas-fir wood containing decay will be lower in bursting strength than those from sound wood in proportion to the amount and type of decay. The bursting strength of the pulp made from wood containing advanced rot would probably be about 75 percent of that of southern pine pulp. (c) Mountain hemlock, noble fir, and lodgepole pine will give pulps with excellent bursting strength and fair tearing strength. (d) Sulfate pulp made from a mixture of 70 percent Douglas-fir, 10 percent mountain hemlock, 10 percent noble fir, and 10 percent lodgepole pine would have a good bursting strength and excellent tearing strength and be of higher quality than pulp made entirely from sound Douglas-fir. (e) Pulp of the quality of that obtained from sound Douglas-fir would be produced from compositions of wood in which either 2.6 parts of wood with incipient decay, 1.7 parts of wood with firm rot, or 1.2 parts of wood with advanced rot are mixed with 1 part of any of the associated species, mountain hemlock, noble fir, and lodgepole pine.

Because of the packing characteristics of the chips, the lower moisture content of the several types of decayed Douglas-fir as compared to that of the sound wood would tend to cause a lower pulp production rate and require an adjustment of the chemical charge in the digester.

Introduction

The experiments described in this report were made for the purpose of determining the suitability of sound (but defective for lumber manufacture) and decayed old-growth Douglas-fir (*Pseudotsuga taxifolia*), mountain hemlock (*Tsuga mertensiana*), noble fir (*Abies procera*), and lodgepole pine (*Pinus contorta* var. *latifolia*) logging and sawmill waste from Oakridge, Oregon, for the production of kraft pulps.

In the Douglas-fir region of Oregon there exists a vast amount of defective old-growth wood with little or no lumber value, and waste wood remaining on the ground in cull material after a logging operation amounting to around 19 cords per acre in some instances. An even larger amount of wood waste is the old-growth Douglas-fir with varying degrees of white pocket. The decay organism, *Fomes pini*, attacks the heartwood portion of the standing tree causing a red heart rot, better known as white pocket. Profitable utilization of these waste materials are necessary to obtain maximum returns from extensive forest stands of this type.

A pulping trial was also made on a sample of extremely decayed Douglas-fir log centers.

In the evaluation of the wood and pulps, all tests and procedures were made according to standard methods of the Technical Association of the Pulp and Paper Industry or those of the Forest Products Laboratory.

The Wood

The wood was received in the form of rough round logs either 4 or 8 feet in length. John B. Grantham of Oregon State College and J. A. Hall, E. E. Matson, and E. G. Locke of the Pacific Northwest Forest and Range Experiment Station assisted in the selection and marking of the sample logs.

The samples of Douglas-fir wood used in the pulping experiments included two types of sound material and four types of infected wood in different stages of decay with white pocket. These six types of Douglas-fir are identified and described as follows:

Lot 1 consisted of small young-growth wood and large old-growth material known as yellow fir. These logs were considered typical of sound, clear wood from small depressed trees and from rough tops from old-growth trees.

Lot 2 consisted of incipiently decayed and stained wood taken from the central areas of defective and culled Douglas-fir.

Lot 3 consisted of firm but partly rotted wood infected with *Fomes pini* taken from the central areas of culled Douglas-fir. This type of material had formerly been used for the production of number 4 common lumber.

Lot 4 contained wood taken from the central areas of the logs in an advance decayed condition with only a small amount of wood with firm rot.

The designation of lot 5 was given to a sample of Douglas-fir received previously to the main shipment. This sample was extremely decayed with white pocket, of honeycomb appearance, and much lower in density than the other lots of decayed wood.

The designation of lot 1A was assigned to wood taken from the rim surrounding the decayed areas of the logs from which lots 2, 3, and 4 were obtained. The material in the rim areas was considered to be sound wood but because it was closely associated with decayed portions in the logs the rim area wood was pulped separately from the sound wood of lot 1.

Wood Evaluation

Preparation of the Wood

Disks 1 inch in thickness were cut from the center of the 8-foot logs and from near the end of the 4-foot pieces for physical tests. The remaining 4-foot lengths were cut to a size to fit the Laboratory chipper. The Douglas-fir logs containing decay were cut in such a manner that pieces of chipper size could be segregated according to lot number and the type of decay previously designated.

The wood of each species was chipped and screened to obtain a quantity of chips nominally five-eighths of an inch in length. A representative sample of the chips from each species was taken for chemical analysis.

Physical Tests on Douglas-fir Wood

The growth and physical test data obtained from sample disks of the several lots of sound and decayed Douglas-fir are recorded in table 1.

The data show that the sound Douglas-fir (lot 1) contained both young- and old-growth groups of logs. The young-growth wood, with an average age of 90 years, consisted of the smaller logs averaging 7.5 inches in diameter inside the bark, whereas the old-growth wood, with an average age of 223 years, consisted of larger logs averaging 17 inches in diameter.

The portions of the logs used to represent material with various degrees of decay were all heartwood and contained no sound wood. However, the whole logs had decayed portions by volume of 52.2 percent for logs containing incipient rot, 56.1 percent for firm rot, and 66.8 percent for advanced rot. The densities of the samples containing the incipient, firm, and advanced rots were similar to that of the sound wood (lot 1).

When pulped the moisture content of each type of decayed wood was much lower than that of either lot of sound wood. Since dry chips pack less densely than moist chips, the drier condition of the decayed parts of the logs would reduce the amount of chips that could be charged into a digester and thereby lower the amount of pulp obtained per digestion.

Chemical Tests on Sound and Decayed Douglas-fir

The data in table 2 on the chemical analysis of Douglas-fir wood indicate that the sound wood surrounding infected areas (lot 1A) and the woods containing incipient, firm, and advanced rots all had essentially the same chemical composition, but they all had definitely lower holocellulose and pentosan contents and a little lower alpha-cellulose content than the sound wood of lot 1. Judged by the chemical composition and the density values of these samples, the extent of the deterioration was less than that indicated by visual examination and less than that required to interfere with normal reactions with sulfate cooking liquors.

Physical Tests on Mountain Hemlock, Noble Fir, and Lodgepole Pine

The growth and physical tests obtained from the sample disks of mountain hemlock, noble fir, and lodgepole pine are given in table 3.

The points of interest about the samples of wood examined were (1) the small diameter and the rather high value for the average rings per inch of growth indicated a suppressed type of wood, (2) the low amount of bark for the lodgepole pine and the high amounts for the mountain hemlock and noble fir, and (3) the slightly higher than normal density of the lodgepole pine. The density values are important factors in the yield of pulp obtainable from a unit volume of wood and in the weight of chips that can be charged to a digester.

The weight of moisture-free wood in a 128-cubic-foot cord of 4-foot rough logs for the noble fir was only 70 percent of that for the lodgepole pine, as shown in the following tabulation:

	Noble fir	Lodgepole pine
Per cord of rough logs:		
Weight of dry wood........lb.	1,755	2,520
Solid volume of wood..cu. ft.	79	92
Number of logs...............	35	55

Chemical Tests on Mountain Hemlock, Noble Fir, and Lodgepole Pine

The chemical analysis data for mountain hemlock, noble fir, and lodgepole pine are given in table 4.

The three species had much lower holocellulose and alpha-cellulose contents than did the sound Douglas-fir. From the standpoint of pulping, any advantage gained by the small amount of extractive material in noble fir would be offset by the disadvantage of the high lignin content of the wood.

Sulfate Pulping

Preparation and Testing of the Pulps

Sulfate pulping experiments were made to produce strong sulfate or kraft-type pulps. For the determination of the yield and strength properties of the pulps portions of the chips equivalent to 4 pounds of moisture-free wood were cooked in 0.5-cubic-foot, steam-jacketed, rotary spherical autoclaves heated indirectly with steam. In all the digestions the cooking schedule consisted of a 1.5-hour temperature increase period from room temperature to the maximum temperature of 170° C. (100 pounds gage pressure) and a 1.5 hour cooking period at that temperature. No spent (black) liquor was used in any of the digestions. Calculations of volumes and chemical concentrations of the cooking liquors included the moisture in the chips. Cooking liquors for all digestions had a sulfidity of 30 percent based on the active alkali (sodium hydroxide plus sodium sulfide both calculated as sodium oxide) present.

After completion of the digestions, the pulped chips from the autoclaves were broken up, thoroughly washed, screened through a 12-cut (0.012-inch slot width) flat screen, pressed to approximately 33 percent dryness, and sampled for moisture. The pulp yields were calculated on a moisture-free basis.

Sulfate Pulping Conditions

Preliminary pulping experiments were made on the sound Douglas-fir wood (lot 1) to establish the optimum conditions with respect to chemical-wood ratio, sulfidity, and liquor-wood ratio. The optimum conditions arrived at are given in table 5. These conditions gave the highest screened yield and pulp strength. The other types of Douglas-fir (and the other species) were pulped under these optimum cooking conditions for the sound Douglas-fir wood. The chemical requirement of 15.6 percent Na_2O or 646 pounds of Na_2O per ton of air-dry pulp for these kraft pulps is in line with present mill practice.

Effect of Degree of Decay

Tables 5, 6, and 7 show the results of pulping under the same cooking conditions sound Douglas-fir and wood decayed to different degrees by Fomes pini. The results indicate that the decayed wood can be satisfactorily reduced to pulp under the same conditions as are required for sound wood. Nearly the same yields of pulps on a weight basis were obtained for all the types of Douglas-fir. The yields of pulp ranged from 43.5 percent for the sound wood of lot 1 to 45.1 for the wood with incipient decay. These yield values are equal to or slightly higher than those reported by Wilkie[4] who obtained yields of only 38 to 40 percent from decayed wood; 41 to 43 percent from sound, old-growth material; and 44 to 46 percent from second-growth Douglas-fir. As measured by the bleach test data and the permanganate number, the pulps from wood with incipient, intermediate, and advanced decay would appear to be easier to bleach than the two types of sound wood.

The moisture contents of the freshly chipped wood were much lower for the several lots of decayed wood (22-23 percent) than for two lots of sound material (33-38 percent). Since the results indicate that the decayed wood can be reduced under the same conditions as are required for sound wood, it appears that the only changes necessary for satisfactory pulping of the lower-moisture-content decayed wood would be in the proper adjustment of the chemical charge to compensate for the decreased amount of wood substance in the digester. This adjustment is necessary so as not to overcook the decayed wood to the detriment of pulp yield and quality.

The chemical composition of the various types of Douglas-fir pulps show that the pulp from decayed wood was considerably higher in alpha-cellulose and lower in lignin and pentosan contents than the pulps from sound wood (lot 1). The high ratio of alpha-cellulose to pentosan contents in the kraft pulps from infected Douglas-fir is much closer to that required in rayon-grade pulps than is usually found in kraft pulps from the sound wood of most pulpwood species.

The bursting strength was the highest for the pulps made from the sound wood (lot 1) and decreased with increasing degree of decay. The pulps from both the sound wood surrounding decayed areas (lot 1A) and the material

[4] Pulp and Paper Industry 20 (3):64-67 (March 1946).

with incipient decay (lot 2) had approximately the same bursting strength. The tensile strength also tended to decrease but the folding endurance showed no definite trend with increase in the amount of decay in the wood. The tearing strengths of the pulps from the sound wood surrounding decayed areas (lot 1A) and from the three lots of decayed material were as high as would be normally expected from sound old-growth Douglas-fir pulpwood and were much higher than those from the sound wood (lot 1). Unfortunately, outstanding tearing strength in a pulp will not offset a low bursting strength when it is judged for quality.

The data indicate that a sulfate pulp from the sound Douglas-fir is slightly lower in bursting strength and significantly higher in tearing strength than southern pine sulfate pulp. It would be expected that the commercial use of this kind of Douglas-fir pulp would be comparable to that of southern pine sulfate pulp. It would not be so useful where high bursting strength or a fine-fibered pulp are needed.

The relative strength properties of the sulfate pulps made from the sound and decayed Douglas-fir and from mixtures of these pulps with those from the other species are discussed later in this report.

Sulfate Pulping of Mountain Hemlock, Noble Fir, and Lodgepole Pine

The pulping tests on mountain hemlock, noble fir, and lodgepole pine consisted of cooking each species under the same cooking conditions as those used for the production of kraft pulps from Douglas-fir. The data for the pulps are also given in tables 5, 6, and 7. Preliminary tests on these woods had indicated that, like Douglas-fir, 15.6 percent active alkali as Na_2O was sufficient for their satisfactory reduction. When produced under the same cooking conditions, the yields of screened kraft pulp from mountain hemlock and lodgepole pine were nearly the same as those from infected Douglas-fir. Under comparable cooking conditions, noble fir gave the highest yield on a weight basis, 47.2 percent, but, because of its rather low density of 22.2 pounds per cubic foot, the lowest yield of pulp on a volume basis of all the materials tested.

The three species gave pulps with excellent bursting and tensile strengths and fairly good tearing strength. The bursting strength of each of these pulps was about equal to that from Western hemlock and higher than that from southern pine.

The chemical composition of the pulps made from mountain hemlock, noble fir, and lodgepole pine were normal for the cooking conditions used. The lower lignin contents and permanganate numbers for the pulps made from lodgepole pine as compared to those made from mountain hemlock and noble fir indicate lower bleach requirements for the lodgepole pine but not so low as for pulps made from decayed Douglas-fir.

Sulfate Pulping of a Mixture of Species

The following mixture of species was made up to simulate that occurring naturally in stands in the Oakridge area:

Wood	Percent (by weight)
Douglas-fir, lot 1	25
Douglas-fir, lot 1A	25
Douglas-fir, lot 2	10
Douglas-fir, lot 3	5
Douglas-fir, lot 4	5
Mountain hemlock	10
Noble fir	10
Lodgepole pine	10

The mixture was pulped with the same amount of cooking chemicals as that used for the individual species. The yield of screened pulp of 45.9 percent on a weight basis for the mixture was not appreciably difference from the value of 44.8 percent calculated from the yields obtained from the individual woods.

The chemical composition of the pulp made from the mixture reflected the effects of the various proportions of the materials in its make-up. In this case, the ratio of alpha-cellulose to pentosan material was lower for the mixture than that for pulps made from the decayed Douglas-fir.

The strength properties of the pulps were also proportionately commensurate with those of pulps prepared from the different woods used in the mixture. The pulp from the mixture had a good bursting strength and excellent tearing strength. It combined the good qualities of the different species to make what should be a very acceptable pulp.

Sulfate Pulping of a Special Sample of Extremely Decayed Douglas-fir Wood

The sample of extremely decayed Douglas-fir (lot 5) was honeycombed and contained a fairly uniform distribution of the white pocket caused by Fomes pini. Its low density of 14.7 pounds per cubic foot was about one-half that of the other Douglas-fir samples tested. As further evidence of its deterioration, the chemical analysis showed a high alkali solubility and losses of alpha cellulose and lignin almost in proportion to the amount of their occurrence in the sound wood.

This wood was pulped under the same cooking conditions as those used for comparing the other decayed woods (table 5). The yield of 41.8 percent screened pulp obtained on a weight basis was only 4 percent lower than that obtained from the sound material and 7 percent lower than those obtained from the other decayed woods. However, owing to its low density the yield expressed on a volume basis of 6.1 pounds per cubic foot of solid wood was 50 percent less than that of the sound material and of the wood with advanced rot.

The pulp made from the extremely decayed wood was much closer in chemical composition to the pulp made from sound wood than to those made from the other decayed woods (table 7).

The pulp made from the extremely decayed wood (lot 5) was (a) equal in bursting strength to that made from wood with advanced decay (lot 4), (b) definitely lower in tearing strength than any of the other Douglas-fir pulps, (c) intermediate in tensile strength between that of pulps made from sound and decayed Douglas-fir and equal to that of the pulp from the sound wood surrounding decayed areas (lot 1A). On the basis of bursting and tearing strength values, the strength of the pulps made from the sample of extremely decayed Douglas-fir was about 75 percent of that made from the sound wood of lot 1, indicating that this kind of wood might be used where high bursting and tearing strengths were not greatly important. This type of material would, of course, be very difficult to handle in the wood room of a pulp mill.

Comparison of Pulps from Douglas-fir and Associated Species and Compounding of Mixtures of Wood for Production of Pulp of Equal Quality

The strength properties of the sulfate pulps made from the various woods were adjusted for a 10 percent loss in strength to account for possible differences between experimental and commercial values and compared with a commercial southern pine pulp on a percentage basis. The results are shown in table 8.

Sulfate pulps made from Douglas-fir wood containing decay were lower in bursting strength than those made from the sound wood in proportion to the amount and type of decay. However, a considerable amount of decayed wood can be present in the Douglas-fir and the lowered strength obtained in the sulfate pulp compensated for by mixing the wood with certain proportions of the associated species (mountain hemlock, noble fir, and lodgepole pine). For example, the reduction in quality caused by the presence of 2.6 parts of wood with incipient decay, 1.7 parts of wood with firm or intermediate decay, or 1.2 parts of wood with advanced decay in the Douglas-fir can be restored by the addition of 1 part of any of the associated species. Therefore, the following compositions of decayed Douglas-fir and associated species will produce sulfate pulp equivalent in quality to that obtained from sound Douglas-fir:

(a) 55 percent advanced-decay Douglas-fir (lot 4) and 45 percent associated species.
(b) 63 percent firm-decay Douglas-fir (lot 3) and 37 percent associated species.
(c) 72 percent incipient-decay Douglas-fir (lot 2) and 28 percent associated species.

A possible composition containing decayed wood and a minimum amount of the associated species that would produce a sulfate pulp having the same quality as one made entirely from sound Douglas-fir might be made up of 65 percent sound wood, 25 percent incipient-decayed wood, and 10 percent associated species.

The sulfate pulp made from the mixture of species compounded in the proportions in which they naturally occur was of higher quality than that made entirely from sound Douglas-fir because of the presence of a higher amount of the associated species. This mixture gave results which compared very favorably with the southern pine sulfate pulp.

Table 1.—Growth and physical characteristics of sound and decayed Douglas-fir logging waste

Wood: Description of sample	Shipment No.	Lot No.	Volume of decayed portion of log	Average diameter	Average age	Average growth rate	Heartwood: Average diameter	Heartwood: By volume	Bark by weight (dry basis)	Density (moisture-free weight and green volume)
			Percent	Inches	Years	Rings per in.	Inches	Percent	Percent	Lb. per cu. ft.
Rough sound wood (8 small logs)	2655	1	0	7.5	90	24.4	5.8	58.2	10.9	30.1
Rough sound wood (4 large logs)	2655	1	0	17.0	223	26.6	14.2	71.0	19.3	26.2
Average (weighted) for sound wood	2655	1	0	10.7	134	25.1	8.6	67.3	14.1	27.4
Sound wood from lots 2,3,4	2655	1-A	0	----	---	42.7	----	60	----	28.6
Incipient rot (Whole logs)			52.2	30.7	286	18.6	27.4	79.6		----
(Decayed portion of logs)	2655	2	----	22.2	137	12.0	----	100.0	----	27.1
Intermediate or firm rot (Whole logs)			56.1	31.2	322	20.7	28.2	82.3		
(Decayed portion of logs)	2655	3	----	23.2	176	14.3	----	100.0	----	28.6
Advanced rot (Whole logs)			66.8	25.3	279	22.4	23.6	87.8		----
(Decayed portion of logs)	2655	4	----	19.6	180	18.3	----	100.0	----	26.4
Centers of extremely decayed logs	2666	5	100.0	----	---	----	----	-----	----	14.7

Table 2.—Chemical analyses of sound and decayed Douglas-fir logging waste

Wood: Description of sample	Wood: Shipment No.	Wood: Lot No.	Cellulose: Holocellulose	Cellulose: Alpha in holocellulose	Lignin	Pentosans: Total	Pentosans: In holocellulose	Solubility in: Alcohol-benzene	Solubility in: Ethyl ether	Solubility in: 1 percent NaOH	Solubility in: Hot water	Ash
			Percent	Percent	Percent	Percent	Percent[1]	Percent	Percent	Percent	Percent	Percent
Sound wood (average all logs)	2655	1	67.0	50.4	27.2	6.8	7.9	4.4	1.2	15.1	5.6	0.2
Sound wood surrounding decayed areas of lots 2, 3, 4.	2655	1A	62.5	48.0	27.6	4.8	4.7	4.4	2.0	12.4	4.1	.3
Incipient rot (decayed portion of log)	2655	2	62.6	47.6	27.8	5.0	5.7	4.2	2.4	14.2	2.2	.1
Intermediate rot (decayed portion of log)	2655	3	63.0	48.4	28.5	4.8	5.6	3.6	1.4	14.3	3.3	.2
Advanced rot (decayed portion of log)	2655	4	64.3	49.0	27.7	4.9	4.8	3.9	1.4	14.1	4.0	.1
Centers of extremely decayed logs	2666	5	67.9	43.1	24.8	6.1	7.1	3.7	.8	20.0	5.6	.1

[1]Results based on holocellulose; all other values are based on moisture-free wood.

Table 3.--Growth and physical characteristics of mountain hemlock, noble fir, and lodgepole pine

Wood: Species	Wood: Shipment No.	Average diameter	Average age	Average growth rate	Heartwood: Average diameter	Heartwood: By volume	Bark by weight (dry basis)	Density (moisture-free weight and green volume)
		Inches	Years	Rings per inch	Inches	Percent	Percent	Pounds per cubic foot
Mountain hemlock	2656	10.2	164	33.5	5.9	38.2	18.3	25.6
Noble fir	2657	9.1	135	30.8	4.6	36.0	26.7	22.2
Lodgepole pine	2658	8.1	159	39.2	6.3	63.7	5.4	27.4

Table 4.—Chemical analyses of mountain hemlock, noble fir, and lodgepole pine

Wood		Cellulose		Lignin	Pentosans		Solubility in —				Ash
Species	Shipment No.	Holocellulose	Alpha in holocellulose		Total	In holocellulose	Alcohol-benzene	Ethyl ether	1 Percent NaOH	Hot water	
		Percent	Percent	Percent	Percent	Percent[1]	Percent	Percent	Percent	Percent	Percent
Mountain hemlock	2656	59.8	42.6	27.0	7.0	7.4	4.6	1.0	11.6	4.8	0.5
Noble fir	2657	61.3	42.8	29.3	9.0	9.2	2.7	.6	9.6	2.3	.4
Lodgepole pine	2658	63.2	43.8	25.0	9.2	8.8	3.5	2.3	12.6	3.6	.2

[1] Results based on holocellulose; all other values are based on moisture-free wood.

Table 5.--Sulfate pulping of sound and decayed Douglas-fir, mountain hemlock, noble fir, lodgepole pine and a mixture of these species

Wood				Digestion No.	Cooking[1] and yield data					Bleach test data	
Species	Description	Lot No.	Moisture content		Chemical consumed	Black liquor density at 15° C.	Yield of pulp (moisture-free)			Brightness	Permanganate No.
							Per 100 pounds of moisture-free wood		Per cubic foot of solid wood (screened pulp)	Pulp bleached with 8.75 percent chlorine	
							Screened	Screenings			
			Percent		Percent	°B.	Lb.	Lb.	Lb.	Percent	
Douglas-fir	Sound (entire logs)	1	37.9	1936, 1937	85.5	11.1	43.5	1.4	11.9	29.4	29.7
Do.........	Sound (outside rim)	1A	33.2	1964, 1965	84.1	11.0	44.6	1.2	12.8	29.4	25.9
Do.........	Incipient decay	2	22.4	1962, 1963	83.9	11.1	45.1	.9	12.2	35.2	24.0
Do.........	Firm rot	3	23.2	1954, 1955	86.9	11.0	44.7	.8	12.8	31.7	22.3
Do.........	Advanced rot	4	23.1	1951, 1952	87.4	11.0	44.9	.8	11.9	33.1	22.5
Do.........	Extreme rot	5	15.7	1934, 1935	90.4	10.8	41.8	1.1	6.1	27.9	29.4
Mountain hemlock	Sound	.....	48.6	1966, 1967	81.8	11.0	45.0	1.1	11.5	30.9	29.1
Noble fir	.......do.........	.....	54.1	1997, 1998	80.4	10.7	47.2	.4	10.5	36.1	28.8
Lodgepole pine	.......do.........	.....	45.6	1974, 1975	81.8	10.7	45.8	.8	12.5	40.4	24.7
Species mixture	....	.....	33.7	2003X, 2004X	83.4	10.9	45.9	1.1	....	35.0	26.9

[1] The cooking conditions other than those outlined are as follows:
Chemicals charged per 100 pounds of moisture-free wood:
Sodium hydroxide and sodium sulfide..............................20.0 pounds.
Calculated as sodium oxide.......................................15.6 pounds.
Initial chemical concentration...................................39.1 grams per liter.
Sulfidity (based on active alkali)...............................30.0 percent.
Liquor-wood ratio.. 4.0

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Table 6.--Strength of sulfate pulps from sound and decayed Douglas-fir, mountain hemlock, noble fir, lodgepole pine, a mixture of these species and southern pine

Wood: Species	Wood: Description	Lot No.	Digestion No.	Bursting strength, Freeness, cc.[2] 450	Bursting strength, Freeness, cc.[2] 250	Tearing strength, Freeness, cc.[2] 450	Tearing strength, Freeness, cc.[2] 250	Tensile strength, breaking length, Freeness, cc.[2] 450	Tensile strength, breaking length, Freeness, cc.[2] 250	Folding endurance, Freeness, cc.[2] 450	Folding endurance, Freeness, cc.[2] 250
				Pts. per lb. per rm.	Pts. per lb. per rm.	Gm. per lb. per rm.	Gm. per lb. per rm.	Meters	Meters	Double folds	Double folds
Douglas-fir	Sound (entire logs)	1	1936, 1937	1.24	1.30	2.48	2.38	7,400	8,300	1,325	1,550
Do.	Sound (outside rim)	1A	1964, 1965	1.14	1.18	3.90	2.87	6,700	7,600	1,425	1,625
Do.	Incipient decay	2	1962, 1963	1.13	1.22	4.18	3.17	6,300	7,100	1,500	2,000
Do.	Firm rot	3	1954, 1955	1.05	1.11	3.43	2.87	6,300	6,900	1,550	2,100
Do.	Advanced rot	4	1951, 1952	.97	1.09	3.80	3.32	5,700	7,200	925	1,550
Do.	Extreme rot	5	1934, 1935	.95	1.07	1.85	1.75	6,800	7,600	875	1,300
Mountain hemlock	Sound	.....	1966, 1967	1.54	1.66	1.53	1.33	9,200	9,200	2,580	2,450
Noble fir	do.	.....	1997, 1998	1.55	1.76	1.85	1.51	10,400	11,100	2,100	2,600
Lodgepole pine	do.	.....	1974, 1975	1.56	1.66	1.72	1.44	8,800	9,400	1,800	3,400
Species mixture	.....	.....	2003X, 2004X	1.37	1.52	2.83	2.40	8,600	9,300	980	1,200
Southern pine	.....	.....	9057-T[3]	1.17	1.25	2.00	1.70	.....	.....	650	800

[1]Test sheets conditioned and tested at 23° C. and 50 percent relative humidity; ream weight of 55 pounds; ream size of 500 sheets each 25 by 40 inches.

[2]Canadian Standard.

[3]Commercial southern pine unbleached kraft pulp.

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Table 7.--Chemical analyses of unbleached sulfate pulps prepared under the same cooking conditions from sound and decayed Douglas-fir, mountain hemlock, noble fir, lodgepole pine and a mixture of these species

Digestion No.	Wood: Species	Wood: Lot No.	Holo-cellulose	Alpha-cellulose	Lignin	Total pentosans
			Percent	Percent	Percent	Percent
1936, 1937	Douglas-fir	1	91.9	77.1	7.7	7.2
1964, 1965	Douglas-fir	1A	95.3	83.3	5.2	5.0
1962, 1963	Douglas-fir	2	98.0	87.7	4.2	4.6
1954, 1955	Douglas-fir	3	95.7	87.5	4.4	4.3
1951, 1952	Douglas-fir	4	95.3	87.1	5.3	4.5
1934, 1935	Douglas-fir	5	92.7	78.6	6.8	5.7
1966, 1967	Mountain hemlock	.....	93.7	77.2	6.2	7.3
1997, 1998	Noble fir	.....	94.2	82.1	6.1	9.0
1974, 1975	Lodgepole pine	.....	94.5	78.5	4.9	9.4
2003X, 2004X	Species mixture	.....	93.4	79.8	5.8	6.6

Table 8.--Comparison of strength of the experimental pulps with commercial southern pine sulfate pulps

Kind of sulfate pulp	Bursting strength	Tearing strength
	Percent	Percent
Southern pine	100	100
Douglas-fir:		
Sound wood from lot 1	95	120
Wood surrounding decayed areas, lot 1A	85	165
Stained wood with incipient rot, lot 2	85	180
Wood with firm rot, lot 3	80	155
Wood with advanced rot, lot 4	75	175
Mountain hemlock	120	70
Noble fir	120	80
Lodgepole pine	120	75
Mixture of species	105	125