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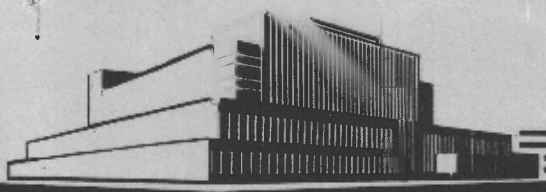
No. 1163

Revised June 1958



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UNITED STATES DEPARTMENT OF AGRICULTURE
FOREST SERVICE
In Cooperation with the University of Wisconsin

GRINDING OF LOBLOLLY PINE. RELATION OF WOOD PROPERTIES AND GRINDING CONDITIONS TO PULP AND PAPER QUALITY[1]

By

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Abstract

In the production of mechanical pulp for newsprint from loblolly pine, wood having a relatively wide range of properties can be used, but the range of grinding conditions is closely limited. For newsprint purposes, the best wood was that with a growth rate of less than 10 rings per inch and an age of less than 35 years. Green wood yielded better pulp than seasoned wood. Knotty wood required more power than clear wood to produce an equivalent product. Blue-stained wood can be used to a limited extent without much detriment to color. Compression wood lowered the strength and color of the pulp in proportion to the amount present. Heartwood in the young, fast-growth pine had no deleterious effect on color or in causing pitch trouble. In the older, slower growing pine, the presence of heartwood caused an increase in strength as compared with the same type of wood without heartwood, but pitch troubles were in evidence and color was poorer whether heartwood was present or not.

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[1] Presented at the Fall meeting of the Technical Association of the Pulp and Paper Industry, DeSoto Hotel, Savannah, Ga., October 18-21, 1937. Originally published in Paper Trade Journal 105(20)41-48, Nov. 18, 1937.

[2] Maintained at Madison, Wis., in cooperation with the University of Wisconsin.

As with other species, the pressure of grinding pine must be adjusted to the sharpness of the stone surface. A dull stone surface, that is, one with well-worn grits and rounded edges on the grooves, seems the most suitable for the grinding of pine. High temperatures were found to have an advantage in increasing the fiber length and strength of the pulp, increasing production, and in lowering power consumption per ton of product, provided the high temperature was attained, not by decreasing the quantity of shower water, but by increasing its temperature so that a normal consistency of 4 to 5 percent was maintained.

The experiments confirm the feasibility of making satisfactory groundwood from southern pine if the wood is properly selected and grinding conditions are carefully controlled.

Introduction

The objective of this work was to determine the influence of the various characteristics of loblolly pine on the properties of the groundwood pulp, and, furthermore, to determine the most suitable grinding conditions for producing a newsprint grade of pulp. In general, the characteristics of loblolly pine are similar to those of all southern pines. Two types of variables were studied:

1. Variables affecting wood properties, which included: (1) the percentage volume of heartwood, (2) the percentage volume of springwood, (3) the rate of growth, (4) knots, (5) seasoning, (6) blue stain, and (7) compression wood.

2. Variables affecting grinding conditions, which included: (1) pressure of wood against the stone, (2) temperature of grinding, (3) consistence of pulp, and (4) stone surface.

The Wood Used and Its Preparation

The loblolly pine used in these experiments was selected from sites near Sumpter, S. C., and Bogalusa, La., and from Washington Parish, La., and Walthall County, Mississippi. The wood was shipped immediately after cutting and the experimental work started shortly after its receipt at Madison, Wisconsin.

Logs between 5 and 6 inches in diameter were selected for the study of the wood variables, such as heartwood content, rate of growth, and the like. The

logs were barked by hand and sawed into pieces 9 inches in length. As many pieces were taken from each log as there were grinder runs to be made in a given series. Ordinarily the wood for one grinder run consisted of 10 pieces, one being taken from each log in the lot. In some of the experiments the pieces were squared so that the pressure of the wood on the stone would be uniform. Care was taken to avoid including large knots or irregularities and also to discard a considerable portion of the dryer ends of the log. Thus each run in a series was made with practically identical wood. The pieces comprising a grinder run were stored in a closed container at a temperatures of 38° F., thereby maintaining the known moisture content until needed.

Equipment and Experimental Procedure

A small 2-pocket grinder carrying a pulp stone 26 inches in diameter with an 11-inch face and equipped with various temperature- and power-measuring instruments was used in these experiments. An artificial stone composed of aluminum oxide abrasive, grit 406, grade K, bond 30 was used in the grinder. This is a relatively coarse-grit stone with a bond of medium hardness.

Since it was desired in a large part of the work to maintain a constant stone surface from series to series, grinder runs were made periodically throughout the course of the experiments under a given set of conditions and with duplicate wood in order to determine whether an appreciable change was occurring in the stone surface. The results indicate that only slight differences can be attributed to stone wear. The effect of varying the stone surface was investigated afterward in a separate series.

Results and Discussion of Experiments

The general properties of groundwood pulp from various types of loblolly pine compared with the average properties of commercial newsprint groundwood pulp are shown in table 1. The details of the experiments are presented in the following paragraphs.

Series 1. Effect of Heartwood

The young, fast-growth wood selected for this series, averaging 9.1 percent of heartwood by volume, was divided into 4 lots, 1 lot for each grinder run. Of one lot one-half the heartwood was bored out, three-quarters from another

lot, all from a third lot, and none from the fourth. The conditions of grinding are shown in table 2. The color of the resulting pulps was practically unimpaired by the presence of heartwood in the quantities existing in these samples (table 3).

A grinder run was then made with squared-off bolts that contained larger quantities of heartwood and were cut from the center of logs that had been stored in the yard 3 months with the bark removed. In this sample the volume of heartwood was 52.1 percent. The resulting pulp was slightly poorer in color than that of the previous runs.

From these tests it may be concluded that, for mechanical pulping, young heartwood in loblolly pine (the diameter of the heartwood in the wood used being less than 2 inches in most cases) is not detrimental so far as pulp color is concerned even though the heartwood is somewhat reddish in color.

The effect of heartwood in older wood with a higher springwood content but of about the same growth rate was determined under somewhat different grinding conditions. The data are given in tables 4 and 5. The wood used in grinder run No. 206 was practically the same in physical properties as that used in grinder run No. 204, that is, it was of slow rate of growth and medium springwood content, except that the wood in grinder run No. 204 contained 40 percent heartwood. The heartwood in this older wood apparently caused a marked increase in the strength of the pulp in relation to the power consumed, as compared with the heart-free material. However, a loss of 2 parts whiteness and 2.6 percent total luminosity in the photometric analysis was caused by the heartwood, and pitch was very evident whether heartwood was present or not.

The age of the wood may be considered as of minor importance yet cannot be wholly neglected, since it is linked up with heartwood formation. Out of 539 logs having a growth rate of less than 11 rings per inch, 33, or 6 percent, were over 35 years of age. The average heartwood content of the 33 logs was 5.1 percent by volume, the maximum being 21.5 percent, in a log 56 years of age, and the minimum 0.1 percent, in a log 36 years of age. The average heartwood content of the 506 logs less than 35 years of age was 1.3 percent by volume, the maximum being 12 percent. Even though the average for all the logs including those greater than 35 years old was only 1.6 percent of heartwood, the younger heartwood seems less deleterious than the older, and therefore it appears that for the best results, the wood should be less than 35 years of age.

Series 2. Effect of Springwood

Two lots of wood of practically equal rates of growth (batches 4 and 5, table 2), containing respectively low and medium volumes of springwood were each

ground at three different pressures. In another lot of wood, batch 6, in which the bolts had all been turned in a lathe to about the same diameter, the rate of growth and volume of springwood of the remaining wood were about equivalent to that of batch 4. The wood in batch 6 was ground at approximately the intermediate of the pressures used in batches 4 and 5. A companion lot of wood, batch 7, also turned in a lathe to the same diameter but with a high volume of springwood in the remaining wood, was ground at the same intermediate pressure. Finally there is included in this series a run on wood, batch 8, of extremely high rate of growth and volume of springwood which was also ground at the intermediate pressure. It may be noted from the data that, in general, higher volumes of springwood yield slightly stronger pulps but at the expense of a slightly increased power consumption. There is also, in general, a slight improvement in the color of the pulp as the volume of springwood is increased.

This was confirmed later in grinder runs Nos. 201, 202, and 203 made with fast-growth wood (table 4). The grinding rate was lower with the high springwood material (grinder run No. 202) than with either the medium springwood (grinder run No. 201) or the low springwood (grinder run No. 203). Since the power input was about the same in all three cases, a higher power consumption per unit of wood ground resulted with the high springwood. There was little variation in the strength of the pulps produced, but the pulp from the pine of high springwood content showed a much lower retention on the 24-mesh screen in the screen analysis test than the other two pulps (table 5).

Grinder runs Nos. 204 and 205 (table 4) were made with slow-growth material containing medium and low contents of springwood, respectively. The material with little springwood ground more slowly than that with medium amounts of springwood, but the power input was also lower so that the power consumption was the same in both cases. The wood with low amounts of springwood produced shorter fibered pulp of lower bursting strength than did the material with medium amounts of springwood (table 5).

It is concluded that while certain advantages may be gained by using wood with high volumes of springwood, they are not marked and may readily be overshadowed by other factors.

Series 3. Effect of Rate of Growth

For this series of experiments two lots of wood (batches 9 and 10, table 2) of slow and medium rates of growth, respectively, were so selected that all other properties were nearly identical. These were each ground at three pressures. Included in the series is the grinder run of the wood, batch 8, mentioned above of extremely high rate of growth and volume of springwood, which was ground at the intermediate pressure.

The effects noted in tables 2 and 3 are that, at the intermediate and high pressures of grinding, the wood of faster growth rate gives pulps with slightly better strength at the expense of increased power per ton of product, but that, on the other hand, at the low pressure, the wood of medium rate of growth gave pulp of better strength with somewhat less power consumption. The pulp from wood with high rate of growth and high volume of springwood (grinder run No. 175) ground at the intermediate pressure was not markedly different in properties than that from the woods of slow and medium rate of growth, or with a medium volume of springwood, ground at that pressure.

Comparing the results of grinder runs shown in tables 4 and 5, made with wood of the same springwood content but of different growth rates, runs Nos. 201 with 204 and run No. 203 with run No. 205, it is evident that the slower growth wood, in spite of the lower power consumption involved, is less desirable than fast-growth wood. The slower growth wood gave pulps with shorter fiber and lower strength per unit of power consumed. The pulps from the slower growth wood were inferior in color, being on the average about three points lower in whiteness. Moreover, greater difficulty was experienced on the wet machine with slow-growth wood because of pitch in the machine felt.

The results indicate, on the whole, that for a quality of pulp suitable for newsprint the rate of growth should not be less than that used in these experiments, that is, about 10 rings per inch, and that the faster the rate of growth the more satisfactory the results are apt to be.

Series 4. Effect of Knots

Wood containing knots and wood free of knots was cut from the same logs. Each was divided into two lots and ground at different pressures. The two lots of knotty wood contained about the same total external knot area.

Knots in the wood appeared to lower the grinding rate (tables 2 and 3), and raise the power consumption but cause slightly stronger pulps to be produced. This is attributed to the probability that the knots, which grind slower than the clear wood, take most of the load and in effect lower the pressure on the surrounding clear wood. Referring to grinder runs Nos. 141 and 142, it is noted that if the pressure on knotty wood is raised sufficiently above that used with the clear wood to give about equal grinding rates the pulps obtained are practically equal in quality, but considerably higher power consumption is required for the knotty wood.

Aside from the consideration of strength and power consumption, it is known, of course, that the presence of much knotty wood introduces an objectionable amount of dirt.

Series 5. Effect of Seasoning

Green loblolly pine containing 44 percent of dry wood (56 percent moisture) was divided into four lots. The first lot was kept green, in a room maintained at 38° F. and 95 percent relative humidity. The other 3 were seasoned in a room controlled at 80° F. and 65 percent relative humidity. One of these lots was raised to a content of 65 percent dry wood and the other 2 to 85 percent.

The effects of grinding the seasoned wood are shown in tables 2 and 3. The drier wood as compared with the green material ground slightly slower, consumed more power per ton, and gave a considerably shorter fibered pulp with lower freeness, but without affecting the strength properties greatly.

One of the lots of wood, which had been dried to a content of 85 percent dry-wood, was afterward soaked in water for several days, but the amount of water taken up was found to be small. A vacuum and pressure treatment was then resorted to in order to drive the water into the wood. After the treatment the wood had a dryness of 46 percent. It was allowed to stand 24 hours in this condition before grinding. It is noted in grinder run No. 167 that the power consumption of this wood was more than that with the original green wood and the strength somewhat better.

The color analysis shows that green wood gives a pulp of better color than that obtained from seasoned wood.

Series 6. Effect of Blue Stain

The wood for the blue-stain experiments was cut into boards 1 inch thick by 2-1/2 inches wide, and then divided into two lots. Both were sterilized with steam at atmospheric pressure for 1/2 hour. One lot was then inoculated with Ceratostomella pilifera, one of the most common blue-stain organisms found in southern pine, and stored in a closed container at normal room temperature and humidity until it was completely stained. The other lot was kept free from stain in a cold room.

Tables 2 and 3 show that there is no appreciable difference in the strength of the pulp from stained and unstained wood. Test sheets made of various mixtures of the two pulps were subjected to photometric analyses. The results shown in table 6 indicate that use of up to 10 percent of blue-stained wood causes a masking of the natural orange tint without loss of whiteness. Blue-stained wood used in the amount of 20 percent or more causes a distinct loss in whiteness.

Series 7. Effect of Compression Wood

A study of the occurrence of compression wood in black spruce and its effect on the quality of groundwood pulp showed it yielded pulp of lower strength and shorter fiber than that obtained from normal wood.[3] Compression wood in pine was found to have similar effects. Certain of the bolts used in grinder run No. 211, table 4, contained large amounts of compression wood. These were segregated from the main lot and ground separately. The data are tabulated as runs Nos. 211-A and 211-C. The wood of run No. 211-B was free from compression wood. It is noted that moderate amounts of compression wood, as indicated in runs Nos. 211 and 211-A (table 5), cause a slight reduction in fiber length and somewhat lowered strength properties in the resulting pulp. Wood consisting all of compression wood, as run No. 211-C, gave a very weak, bulky pulp of poor color.

Series 8. Effect of Pressure

Wood of medium rate of growth and low volume of springwood was ground under various pressures. The effects noted in tables 7 and 8 agree with that experienced on other species. For the given stone surface and temperature, the power consumption and the strength of the pulp drop considerably with rising pressure. There is also a substantial increase in the production rate and freeness and a slight increase in the fiber length as indicated by the screen analysis test. For pine, as in the grinding of other woods, the pressure must be adjusted according to the stone surface in order to obtain the desired results.

Series 9. Effect of Stone Surface

It has been reported that a good stone surface for use in grinding southern pine is obtained with a combination of a 9-cut, 4-1/2-inch lead spiral burr and a 4-cut straight burr.[4] After completion of grinder run No. 175, burrs of these types were applied to the stone and followed with a wearing-in period of 60 hours on miscellaneous wood. Several grinder runs were then made under various conditions. Referring to the series in tables 7 and 8 and comparing results of grinder runs Nos. 132 with 177, and 122 with 176, it is noted that under the same grinding conditions the new surface gave pulp of poorer strength, but lower power consumption than the previous surface, indicating it was sharper.

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[3] Pillow, M. Y., Schafer, E. R., and Pew, J. C. Occurrence of Compression Wood in Black Spruce and Its Effect on Properties of Groundwood Pulp. Paper Trade J. 102, No. 16; 36 - 1936.

[4] Herty, C. H. Wood in the South for Newsprint. Paper Mill and Wood Pulp News, 58, No. 2; 20 - 1935.

Grinding at a lower pressure with the new stone surface (run No. 179) gave about the same power consumption as a higher pressure on the previous surface (run No. 168). When the new surface had been well worn in and used with a higher pressure (grinder run No. 201) a pulp of much better quality was obtained.

These tests, while not extensive, indicate as pointed out previously, that the pressure to be used depends on the sharpness of the stone surface. It furthermore appears that the pattern is secondary to the condition of the surface and that a surface with well-worn grits and rounded edges on the grooves seems the most suitable for the grinding of pine.

Series 10. Effects of Temperature and Consistency

The effect of the temperature of grinding loblolly pine has been reported.[5, 6] Briefly it was found that the grinding process was favored by high temperatures, provided high consistencies are avoided by the use of warmed shower water. Increasing the plasticity of the wood by preheating it in water to the grinding temperature had relatively small effect as compared with elevating the pit temperature. It is believed that much benefit may be obtained, not only in the grinding of pine but in grinding other species as well, by conserving the heat of grinding and returning it to the grinder in white water at higher temperatures than customarily employed. The advantageous effect of a higher temperature noted in the work referred to prompted the use of a temperature of 190° F. in the supplementary work shown in tables 4 and 5.

Miscellaneous Tests for Comparison

In tables 7 and 8 are shown several tests made for comparison with the pine experiments. Grinder runs Nos. 169 and 170 were made with black spruce in the green condition. Comparing the results with those obtained in somewhat similar runs on pine (grinder runs Nos. 144 and 145, series 8), it is seen that for an equal power consumption on this stone surface, higher pressures are required with spruce, which not only grinds faster but yields pulps

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[5] Schafer, E. R. and Pew, J. C. Effect of Temperature and Consistency in Mechanical Pulping. Paper Trade J. 101, No. 13;71 - 1935.

[6] Schafer, E. R., Pew, J. C., and Knechtges, R. G. Effect of High Pit Temperatures and of Preheating of the Wood on the Grinding of Loblolly Pine. Paper Trade J. 103, No. 2; 29 -1936. TS 41.

of much higher strength. In grinder run No. 170 (black spruce) pulp of higher than average quality was produced at somewhat below average power consumption.

Comparison of the pulp from grinder run No. 168 (series 9) with the commercial spruce pulps P 1037 and P 1101 indicates that this pine pulp is equal to the commercial pulps insofar as pulp tests are concerned. The pulps from grinder runs Nos. 201, 202, 203, and 211 (table 4) also compare very favorably with these commercial pulps in all strength, color, and suspension properties (table 5).

Newsprint Paper Tests

The pulp from grinder run No. 211 prepared from fast-growth wood was made into newsprint papers which were standard in every respect. The groundwood was combined with either pine sulphite or pine semibleached kraft. A groundwood pulp made from slow-growth pine wood was combined with semibleached kraft and made into a newsprint sheet that was satisfactory from the standpoint of strength and finish and only slightly darker in color than average newsprint.

Table 1. --General properties of groundwood pulp from various types of loblolly pine compared to the average of commercial newsprint groundwood pulp

Rate of growth	Springwood content	Pulp of loblolly pine without heartwood				Pulp of loblolly pine with heartwood			
		Power consumed	Strength	Color	Pitch	Power consumed	Strength	Color	Pitch
Fast	High	Slightly above average	Good	Good	No evidence	No tests	(1)	(1)	(1)
	Medium	Average	Good	Good	No evidence	Average	Good	Good	No evidence
	Low	Average	Good	Good	No	No tests	(1)	(1)	(1)
Slow	Medium	Slightly below average	Fair	Fair	Some evidence	Average	Good	Poor	Very evident
	Low	Slightly below average	Fair	Fair	Some evidence	No tests	(1)	(1)	(1)

[1] No tests -- probably same as for medium springwood.

Table 2.--Effect of wood properties on the grinding of loblolly pine

Grinder run	Batch[2]	Average properties of the wood						Grinding conditions[1]					
		Classification	Volume of heartwood	Volume of springwood	Rate of growth	Dryness	Density dry weight/green volume	Age	Service of stone since last burring[3]	Pressure of wood on stone[4]	Grinding rate: Dry wood per 24 hours	Power input	Energy consumption[5]
No.	No.		Percent	Percent	Rings per inch	Percent	Lb. per cu. ft.	Years	Hours	P.s.i.	Tons	Hp.	Hp. days
SERIES 1.--EFFECT OF HEARTWOOD													
123	2	Heartwood free	0	58.7	9.2	51.0	30.1	29.0	120.5	27	1.05	44.5	42.3
126	2	Containing heartwood	2.3						122.0	27	1.02	48.3	47.2
125	2	Containing heartwood	4.5						121.5	27	1.05	48.8	45.4
124	2	Containing heartwood	9.1						121.0	27	.96	45.1	46.6
149	3	Containing heartwood	52.1	(7)	(7)	78.0	26.3	(7)	138.6	26	.59	36.6	61.2
SERIES 2.--EFFECT OF SPRINGWOOD													
127	4	Low springwood	.1	54.8	5.5	47.7	29.4	15.7	122.5	28	.98	45.1	45.0
129	4	Low springwood							123.5	21	.65	33.8	51.0
131	4	Low springwood							124.7	14	.33	26.9	72.5
147	6	Low springwood	.3	56.4	4.9	48.4	30.8	16.0	137.4	21	.62	37.3	63.2
128	5	Medium springwood	.7	67.9	5.0	42.5	25.3	13.5	123.0	28	.89	39.1	43.7
130	5	Medium springwood							124.1	21	.58	37.6	64.2
132	5	Medium springwood							126.0	13	.30	28.4	93.0
148	7	High springwood	0	78.5	3.7	37.0	23.6	13.0	138.1	21	.70	39.1	55.3
175	8	High springwood	0	83.5	2.1	36.3	23.4	6.3	157.3	21	.60	41.6	68.3
SERIES 3.--EFFECT OF RATE OF GROWTH													
133	9	Slow rate	1.5	60.4	10.0	49.0	29.6	27.0	127.2	28	.86	38.4	44.5
135	9	Slow rate							128.2	21	.60	34.7	57.2
137	9	Slow rate							129.5	13	.30	27.1	90.5
134	10	Medium rate	.6	61.5	4.8	44.9	27.8	13.0	127.6	28	.79	44.8	56.3
136	10	Medium rate							128.8	21	.56	34.5	60.8
138	10	Medium rate							130.9	13	.32	26.5	82.3
175	8	Fast rate	0	83.5	2.1	36.3	23.4	6.3	157.3	21	.60	41.6	68.3
SERIES 4.--EFFECT OF KNOTS													
140	11	Knotty wood[8]	.1	65.1	6.5	44.0	27.2	18.7	132.7	20	.42	38.0	89.8
142	11	Knotty wood[8]							134.7	28	.60	51.4	85.3
141	11	Clear wood							133.9	20	.56	35.1	62.9
143	11	Clear wood							135.5	28	.90	48.2	53.2
SERIES 5.--EFFECT OF SEASONING													
164	12	Green	.1	60.6	5.4	44.0	27.9	14.8	149.0	21	.58	37.4	63.9
165	12	Seasoned				65.0			149.6	21	.56	37.2	66.2
166	12	Seasoned				85.0			150.5	21	.49	34.5	70.7
167	12	Seasoned and resoaked				46.2			151.4	21	.52	38.5	73.2
SERIES 6.--EFFECT OF BLUE STAIN[9]													
173	13	Blue stained[10]	(7)	(7)	(7)	40.8	(7)	(7)	156.0	25	.52	32.8	62.5
174	13	Not blue stained				40.8			156.7	25	.50	36.3	72.5

[1] Constant conditions: shower water temperature, 80° F.; pit temperature, 150° F.; pit consistency 3 to 5 percent.

[2] Except as otherwise indicated, identical wood was used in grinder runs associated with the same batch number. Hence, to avoid repetition the properties of each batch of wood are recorded only once in each series; that is, opposite the grinder run in which it was first used.

[3] The aluminum oxide grindstone had been dressed with a 10-cut, 1-1/4-inch lead spiral burr and in service 120 hours before the start of the experiments. Check runs made periodically throughout the course of the experiments indicated only slight change in stone wear.

[4] The cylinder pressure was corrected for the friction loss in the pistons and piston rod glands and reduced to the average unit pressure of wood against stone using the average lengths and diameter of the bolts of wood as a basis for calculation.

[5] Energy consumption is based on wood instead of pulp because of excessive losses of fiber on the wet machine.

[6] Strength tests were made with sheets of approximately 115 pounds per ream of 500 sheets each 25 x 40 inches.

[7] Not determined.

[8] The surface area of knots in the knotty wood of this batch was about 2.8 percent of the total area of the bolts exclusive of the ends.

[9] See also table 6.

[10] Blue stained by inoculation with Ceratostomella pilifera.

Table 3.--Effect of wood properties on the grinding of loblolly pine

Grinder run No.	Properties of pulp suspension: Screen analysis: Freeness Schopper Riegler, cc.	Retained on 24-mesh, Percent	Passing 150-mesh, Percent	Fiber length index, Mm.	Properties of pulp test sheets: Bursting strength, Pts. per lb. per ream[1]	Tearing strength, Gms. per lb. per ream[1]	Tensile strength, P.s.i.	Solid fraction	Color analysis: Ives blue[2]	Primary hue[2], Percent	Secondary hue[2], Percent	Total luminosity, Percent
SERIES 1.--EFFECT OF HEARTWOOD												
123	335	2.8	55.0	0.078	0.10	0.38	687	0.26	66	4.5-0	4.1-Y	74.6
126	330	2.8	55.4	.078	.10	.44	637	.27	66	4.5-Y	3.8-0	74.3
125	330	2.5	59.0	.075	.09	.42	605	.27	65	5.1-0	3.6-Y	73.7
124	330	3.4	54.6	.078	.10	.37	755	.27	66	4.5-Y	3.8-0	74.3
149	300	2.9	55.7	.079	.12	.54	742	.25	64	5.8-0	4.1-Y	73.9
SERIES 2.--EFFECT OF SPRINGWOOD												
127	360	2.9	52.4	.081	.11	.38	657	.25	67	7.0-0	.5-Y	74.5
129	303	2.5	57.1	.077	.12	.39	950	.27	64	5.8-0	4.1-Y	73.9
131	238	1.8	56.1	.077	.17	.45	1,163	.28	62	6.4-0	1.8-Y	70.2
147	303	3.1	54.7	.079	.14	.40	830	.27	65	5.8-0	5.0-Y	75.8
128	325	1.7	52.7	.080	.12	.38	746	.26	71	5.1-0	1.8-Y	77.9
130	248	2.5	55.1	.079	.15	.45	1,150	.27	64	5.8-0	1.4-Y	71.2
132	197	0.8	57.7	.075	.19	.48	1,487	.30	66	5.1-0	2.7-Y	73.8
148	326	2.5	48.7	.085	.12	.53	788	.26	69	4.5-0	3.2-Y	76.7
175	255	2.8	51.5	.083	.17	.42	987	.28	70	5.1-0	1.8-Y	76.9
SERIES 3.--EFFECT OF RATE OF GROWTH												
133	345	3.4	52.6	.081	.11	.32	648	.25	61	5.9-Y	4.5-0	71.4
135	290	2.7	55.4	.078	.14	.33	885	.27	65	5.0-Y	3.2-0	73.2
137	188	0.6	62.7	.072	.17	.32	1,217	.29	63	5.1-0	3.6-Y	71.7
134	302	2.7	50.2	.083	.14	.30	822	.26	63	3.2-0	1.3-Y	67.5
136	278	1.1	57.8	.076	.16	.34	945	.28	62	5.1-0	4.5-Y	71.6
138	213	2.3	67.5	.070	.20	.31	1,302	.30	65	4.5-0	2.3-Y	71.8
175	255	2.8	51.5	.083	.17	.42	987	.28	70	5.1-0	1.8-Y	76.9
SERIES 4.--EFFECT OF KNOTS												
140	172	0.9	62.4	.072	.19	.40	1,571	.30	67	5.8-0	.5-Y	73.3
142	185	0.7	69.8	.067	.17	.36	1,260	.29	65	5.8-0	2.3-Y	73.1
141	230	1.2	65.3	.071	.18	.36	1,220	.29	66	5.0-Y	3.2-0	74.2
143	305	2.0	58.7	.076	.14	.38	989	.27	66	5.1-0	.4-R	71.5
SERIES 5.--EFFECT OF SEASONING												
164	323	3.2	50.7	.082	.13	.52	920	.27	66	5.1-0	2.7-Y	73.8
165	275	2.4	55.8	.077	.15	.55	1,141	.28	62	5.8-0	3.2-Y	71.0
166	212	1.4	62.6	.072	.15	.43	1,138	.29	62	5.8-0	2.3-Y	70.1
167	255	2.5	56.8	.078	.16	.54	1,036	.28	61	5.9-Y	4.5-0	71.4
SERIES 6.--EFFECT OF BLUE STAIN[4]												
173	300	8.0	46.4	.090	.22	.60	1,173	.28	56	5.1-0	.9-Y	62.0
174	255	7.8	47.5	.089	.21	.69	987	.28	67	4.5-0	2.3-Y	73.8

[1] Strength tests were made with sheets of approximately 115 pounds per ream of 500 sheets each 25 x 40 inches.

[2] The degree of whiteness is indicated by the lowest of the Ives reading (red, green, and blue) which was the blue for all pulps recorded here.

[3] The tint is designated as follows: Y, yellow; O, orange; R, red.

[4] See also Table 6.

Table 4.--Supplementary tests on the effect of wood properties on the grinding of loblolly pine

Grinder run No.	Classification	Average properties of the wood: Rate of growth (Rings per inch)	Volume of springwood (Percent)	Volume of heartwood (Percent)	Dryness (Percent)	Density, dry weight per green volume (Lbs. per cu. ft.)	Age (Years)	Grinding conditions[1]: Service of stone since last burring[2] (Hours)	Pressure of wood on stone[3] (P.s.i.)	Grinding rate: Dry wood per 24 hours (Tons)	Power input (Hp.)	Energy consumed per ton dry wood (Hp. days)
201	Rapid growth--medium springwood	3.3	66	0	40.7	26.6	17.0	175.0	25.0	0.57	39.7	70.2
202	Rapid growth--high springwood	2.2	80	0	39.2	23.9	6.9	175.8	25.0	.51	41.6	80.9
203	Rapid growth--low springwood	2.7	50	0	49.0	30.4	20.0	177.8	25.0	.56	40.6	71.5
204	Slow growth--medium springwood	9.7	64	0	48.8	29.7	41.7	180.3	25.0	.61	40.1	65.3
205	Slow growth--low springwood	10.3	49	0	52.2	33.2	54.0	185.3	25.0	.56	36.9	65.3
206	Slow growth--medium springwood containing heart	11.0	65	40.0	53.7	28.3	57.7	187.5	25.0	.57	40.6	71.7
211	Rapid growth--medium springwood--11 per percent compression wood	2.4	63	.9	43.4	26.8	12.8	238.8	25.0	.57	49.8	87.5
211-A[4]	Rapid growth--25 percent compression wood								25.0	.53	50.3	91.4
211-B[4]	Rapid growth--no compression wood								25.0	.51	47.6	93.5
211-C[4]	Rapid growth--all compression wood								25.0	.91	55.2	60.4

[1] Constant conditions: shower water temperature 111° - 126° F.; pit temperature 190° F.; pit consistency 4 - 5.5 percent.

[2] An aluminum oxide stone grade 406-K 30, dressed with a 9-cut, 4-1/2-inch lead spiral burr followed by a 4-cut straight burr.

[3] In runs Nos. 201 to 206, inclusive, the wood was cut into rectangular blocks 6 inches wide and 9 inches long. The pressure of the wood against the stone was calculated from the actual thrust delivered by the pressure foot, connected for friction loss in glands, and the area of the block facing the stone. In run No. 211 the bolts were 10 to 12 inches in diameter and therefore had to be cut down on two sides to fit into the 8-inch wide grinder pocket.

[4] Wood used was certain of the bolts segregated from the rest of the wood while making run No. 211. Data for run No. 211 includes the wood used in these runs.

Table 5.--Supplementary tests on the effect of wood properties on the grinding of loblolly pine

Grinder run	Properties of pulp suspension				Properties of pulp test sheet[1]							
	Freeness: Schopper-Riegler	Screen analysis: Retained on 24 mesh	Screen analysis: Passing 150 mesh	Fiber length index of pulp	Bursting strength	Tearing strength	Tensile strength	Solid fraction	Color analysis: Ives blue[2]	Color analysis: Primary hue[2]	Color analysis: Secondary hue[2]	Color analysis: Total luminosity
No.	Cc.	Percent	Percent	Mm.	Pts. per lb. per ream[1]	Gms. per lb. per ream[1]	P.s.i.		Parts	Percent and tint	Percent and tint	Percent
201	272	20.9	39.5	0.103	0.22	0.72	953	0.23	62	5.8-0	4.1-Y	71.9
202	208	11.1	44.7	.093	.22	.80	1,180	.25	65	4.5-0	4.1-Y	73.6
203	218	19.4	42.9	.098	.24	.77	1,095	.24	65	5.1-0	3.6-Y	73.7
204	298	11.3	43.9	.092	.15	.53	848	.24	62	5.8-0	5.0-Y	72.8
205	288	6.4	50.5	.083	.12	.52	864	.25	61	7.0-0	4.1-Y	72.1
206	273	14.1	43.4	.094	.20	.64	1,075	.24	60	7.0-0	3.2-Y	70.2
211	200	15.2	46.1	.093	.24	.73	1,143	.24	66	4.5-0	4.1-Y	74.6
211-A	.....	10.4	49.4	.087	.23	.65	1,145	.25	66	5.1-0	2.7-Y	73.8
211-B	.....	14.8	45.2	.094	.27	.74	1,376	.26	66	5.1-0	3.6-Y	74.7
[4]211-C	255	7.1	46.6	.088	.09	.39	463	.20	61	6.4-0	3.6-Y	71.0

[1] Strength tests made on sheets of about 115 pounds per ream of 500 sheets each 25 x 40 inches.

[2] The degree of whiteness is indicated by the lowest of the Ives readings (red, green, and blue) which was the blue for all pulps recorded here.

[3] The tint is designated as follows: O, orange; Y, yellow.

[4] Tests made on slush pulp taken at grinder dam. All other tests were made on samples taken at the wet machine.

Table 6.--Color analysis of mixtures of pulps from Series 6 containing various amounts of blue stain

Pulp mixtures		Ives blue[1]	Primary hue[2]	Secondary hue[2]	Total luminosity
Blue-stained wood[3]	Unstained wood[4]				
Percent	Percent	Parts	Percent and tint	Percent and tint	Percent
0	100	67	4.5-0	2.3-Y	73.8
5	95	67	4.5-Y	1.3-0	72.8
10	90	67	2.6-0	1.8-Y	71.4
20	80	65	2.6-0	1.8-Y	69.4
30	70	63	3.2-0	1.4-Y	67.6
50	50	60	3.2-0	2.3-Y	65.5
100	0	56	5.1-0	0.9-Y	62.0

[1] The degree of whiteness is indicated by the lowest of the Ives readings (red, green, and blue) which was the blue for all pulps recorded here.

[2] The tint is designated as follows: Y, yellow; 0, orange.

[3] From Grinder run 173.

[4] From Grinder run 174.

Table 7.--Effect of pulping variables in the grinding of loblolly pine

Grinder run No.	Batch[2] No.	Classification	Average properties of the wood: Volume of heartwood, Percent	Volume of springwood, Percent	Rate of growth, Rings per inch	Dryness, Percent	Density dry weight/green volume, Lb. per cu. ft.	Age, Years	Grinding conditions[1]: Service of stone since last burring[3], Hours	Pressure of wood on stone[4], P.s.i.	Grinding rate: Dry wood per 24 hours, Tons	Power input, Hp.	Energy consumption[5], Hp. days
		SERIES 8.--EFFECT OF PRESSURE											
131	4	Low springwood	0.1	54.8	5.5	47.7	29.4	15.7	124.8	14	0.33	26.9	72.5
144	14	Low springwood	.4	58.5	5.3	46.2	28.9	15.1	136.0	21	.63	39.1	62.3
127	4	Low springwood							122.5	28	.98	45.1	45.0
145	14	Low springwood							136.8	36	1.26	51.5	40.6
146	14	Low springwood							137.2	50	1.92	71.7	37.2
		SERIES 9.--EFFECT OF STONE SURFACE[6]											
132	5	Medium springwood	.7	67.1	5.0	42.5	25.3	13.5	126.0	13	.30	28.4	92.5
177	20	Medium springwood	.3	63.8	4.7	42.7	26.7	13.1	60.5	14	.34	25.9	71.6
122	1	Medium springwood	.6	61.0	5.1	45.0	27.6	14.3	120.0	28	.92	44.0	47.2
176	1	Medium springwood							60.0	28	.85	37.1	40.0
146	14	Low springwood	.4	58.5	5.3	46.2	28.9	15.1	136.8	50	1.92	71.7	37.2
178	20	Medium springwood							61.6	42	1.35	51.7	32.9
168	19	High springwood	0	72.0	4.1	41.8	25.4	10.5	150.5	13	.26	23.6	89.2
179	20	Medium springwood							61.9	14	.28	24.3	76.4
180	20	Medium springwood							63.1	14	.36	24.9	64.8
201		Medium springwood	0	66.0	3.3	40.7	26.6	17.0	175.0	25	.57	39.7	70.2
		MISCELLANEOUS TESTS FOR COMPARISON											
169	21	Black spruce	78.3	74.8	13.7	62.4	26.4	44.0	153.8	21	.39	42.2	96.1
170	21	Black spruce							155.0	35	.97	55.1	56.8
P1037		Commercial spruce groundwood											
P1101		Commercial spruce groundwood											

[1] Pit consistency 2.9 to 5.9 percent; pit temperature in grinder run No. 170, 160° F., in runs Nos. 168, 179, and 201, 190° F., in run 180, 200° F., and in all others 150° F.

[2] Identical wood was used in grinder runs associated with the same batch number. Hence, to avoid repetition the properties of each batch of wood are recorded only once in each series; that is, opposite the grinder run in which it was first used.

[3] Except for series 9, an aluminum oxide grindstone was used that had been dressed with a 10-cut, 1-1/4-inch lead spiral burr and in service 120 hours before the start of the experiments.

[4] The cylinder pressure was corrected for the friction loss in the pistons and piston rod glands and reduced to the average unit pressure of wood against stone using the average lengths and diameter of the bolts of wood as a basis for calculation.

[5] Power consumption is based on wood instead of pulp because of excessive losses of fiber on the wet machine.

[6] For grinder runs Nos. 122, 132, 146, and 168, an aluminum oxide grindstone was used that had been dressed with a 10-cut, 1-1/4-inch lead spiral burr and in service 120 hours before the start of the experiments. Before grinder runs Nos. 176 to 180, inclusive, the stone had been dressed with a 9-cut, 4-1/2-inch lead spiral burr and in service 60 hours. The surface at this time was sharp but near the point beyond which change was expected to be slow.

Table 8.--Effect of pulping variables in the grinding of loblolly pine

Grinder run	Properties of pulp suspension				Properties of pulp test sheets							
	Screen analysis				Bursting strength	Tearing strength	Tensile strength	Solid fraction	Color analysis			
	Freeness: Schopper: Riegler	Retained on 24-mesh	Passing 150-mesh	Fiber length index					Ives blue[2]	Primary hue[2]	Secondary hue[2]	Total luminosity
No.	Cc.	Percent	Percent	Mm.	Pts. per lb. per ream[1]	Gms. per lb. per ream[1]	P.s.i.		Parts	Percent and tint	Percent and tint	Percent
					SERIES 8.--EFFECT OF PRESSURE							
131	238	1.8	56.1	0.077	0.17	0.45	1,163	0.28	62	6.4-0	1.8-Y	70.2
144	303	2.8	56.8	.078	.15	.38	844	.26	68	5.1-0	.....	73.1
127	360	2.9	52.4	.081	.11	.38	657	.25	67	7.0-0	0.5-Y	74.5
145	412	3.3	47.5	.086	.10	.31	702	.25	66	5.1-0	1.1-R	72.2
146	493	3.6	46.8	.087	.08	.27	362	.21	64	5.8-0	3.2-Y	73.0
					SERIES 9.--EFFECT OF STONE SURFACE[4]							
132	197	0.8	57.7	.075	.19	.48	1,487	.30	66	5.1-0	2.7-Y	73.8
177	227	1.0	58.0	.075	.14	.32	1,039	.28	64	5.1-0	2.7-Y	71.8
122	350	1.7	53.7	.079	.11	.39	725	.26	68	5.1-0	0.2-R	73.3
176	375	1.1	58.0	.075	.08	.27	648	.25	62	5.1-0	3.2-Y	70.3
146	493	3.6	46.8	.087	.08	.27	362	.21	64	5.8-0	3.2-Y	73.0
178	368	1.2	55.3	.077	.05	.23	420	.23	64	5.1-0	2.7-Y	71.8
168	190	6.1	48.4	.088	.25	.68	1,408	.28	65	5.8-0	2.3-Y	73.1
179	238	3.6	50.8	.083	.18	.46	1,073	.26	66	3.8-0	3.6-Y	73.4
180	252	5.3	49.4	.085	.18	.51	981	.27	63	5.8-0	1.4-Y	70.2
201	272	20.9	39.5	.103	.22	.72	953	.23	62	5.8-0	4.1-Y	71.9
					MISCELLANEOUS TESTS FOR COMPARISON							
169	158	7.1	52.8	.083	.39	.67	2,530	.34	69	3.8-0	2.7-Y	75.5
170	230	15.4	46.0	.092	.30	.84	1,512	.28	70	3.8-0	1.8-Y	75.6
P1037	230	5.4	69.8	.069	.21	.63	950	.22	71	5.1-0	1.8-Y	77.9
P1101	375	18.0	40.7	.101	.24	.71	1,273	.28	57	5.8-0	2.3-Y	65.1

[1] Strength tests were made with sheets of approximately 115 pounds per ream of 500 sheets each 25 x 40 inches.

[2] The degree of whiteness is indicated by the lowest of the Ives reading, (green, red, and blue) which was the blue for all pulps recorded here.

[3] The tint is designated as follows: Y, yellow; O, orange; R, red.

[4] The pattern of the stone surface for grinder runs Nos. 122, 132, 146, and 168 was as described in Table 1, footnote 3. Prior to grinder runs Nos. 176 to 180, inclusive, the stone had been dressed with a 9-cut, 4-1/2-inch lead spiral burr and in service 60 hours. The surface at this time was sharp but near the point beyond which change was expected to be slow.