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Chip Quality Survey

for Sawmills in the Southeastern United States

FINAL REPORT

MAFES
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Chip Quality Survey for Sawmills in the Southeastern United States

Final Report

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Snider Forest Industies
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T&S Hardwoods
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Varn Wood Products
Wade Wood

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Introduction

In 1988, 106 pulp mills located in the U.S. South had a productive capacity of 126,267 tons of pulp per day. Based on data from a census of pulp mills, their output in 1988 required 41.4 million cords of roundwood and 20.7 million cords of mill chip products from primary wood-using industries such as sawmills and veneer mills (Figure 1). Wood chips used by these pulp mills are obtained from a variety of sources, including those produced by sawmills[1]. In 1988, softwood chip products from sawmills, plywood, and planer mills constituted 25 percent of the total fiber supply required by pulp mills in the U.S. South with hardwood chip products constituting 8 percent.

Hatton, in a series of articles, presented study results examining wood chip quality in the Pacific Northwest from various sawmill chipping equipment. Hatton (1975a) reported that sawmills produced more fines and pin chips and fewer oversized chips as compared to roundwood disc chippers in woodyards. Hatton's results corroborated those of Galloway and Thomas (1972). Furthermore, average chip thickness of the acceptable chip fraction (2-8mm) was lower for sawmill chips than roundwood disc chippers (Hatton 1976). However, sawmill chips had lower packing densities than woodyard chips and Hatton suggested that kraft pulping could be optimized by blending sawmill and woodyard chips.

Hatton (1975b) demonstrated the seasonal effects on chip distributions. Fines and pin chips were minimized during the summer months and increased to their highest levels in the winter months during periods with frozen logs. These results have been corroborated by Stuart and Leary (1991) and are consistent with experiences of production-oriented woodyards.

Increased competition for fiber from woodlands, increased market demands for consistent quality of pulp and paper products, and the demand for greater economic returns from pulp and paper operations are the impetus for a heightened interest in the quality of wood chips as the fiber supply of the pulp and paper industry.

Quality of wood chips entering a pulp digesting system is of utmost importance to the pulp and paper industry because wood quality is the dominant factor determining pulp quality (Fahey, 1990). Wood chip quality specifications vary by the specific pulping system (batch, continuous, etc.), but the minimization of contaminants such as bark, rot, and dirt in a wood chip supply is desirable for all pulping systems. Contaminants have detrimental physical and economic impacts. Bark in a wood chip supply lowers pulp yields, increases the use of chemicals, and often degrades paper quality, while rot lowers pulp yields and pulp strength (Fahey, 1990). Minimizing the amount of very small and oversized wood chips is also important to chip quality regardless of the pulping system. Uniformity of chip size allows for a more uniform and

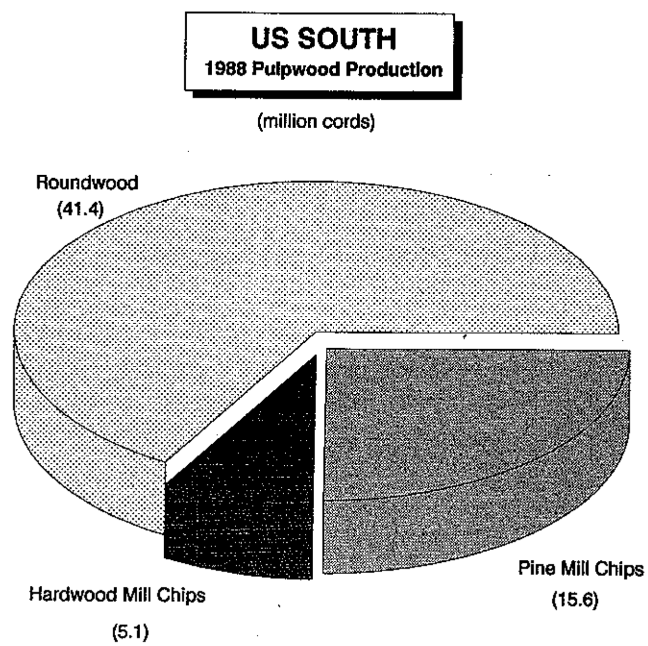


Figure 1. Total pulpwood production by source in the U.S. South, 1988. (Source: USDA Forest Service 1991.)

This paper is an updated version from the original, which was presented at the 1991 TAPPI Pulping Conference, Orlando, FL, November 3-7, Copyright TAPPI 1991 (Dubois, Watson, and Wagner, 1991); and the 1991 American Society of Agricultural Engineer's National Forest Engineering Conference, New Orleans, LA, June 5-6, 1991 (Dubois, Koger, and Watson, 1991).

[1]The term sawmill chip products is used throughout this manuscript to differentiate between processed chip products and unprocessed materials such as sawmill residues in the form of board edgings, slabs, and lumber trim blocks.

consistent pulping resulting in an improved finished product.

For the purpose of this study, chip quality refers exclusively to chip size. Data recently collected on chip products from sawmills enable an analysis of chip quality as it is affected by sawmill processes. Pine mill and hardwood mill will be considered separate. Specific objectives of the study were to:

(1) Develop the conversion relationships between lumber production and wood chip production for pine and hardwood sawmills.

(2) Identify and characterize equipment and processes used by pine and hardwood sawmills in the production of wood chips.

(3) Identify and characterize equipment and processes used by pine and hardwood sawmills as they affect wood chip quality.

(4) Compare hardwood and pine chip quality from sawmills to wood chips produced by woodland and woodyard production sources.

Data Collection

Questionnaires were used to collect information about the operating characteristics of pine and hardwood sawmills located in 10 southern states (Figure 2). A copy of the questionnaire is presented in Appendix A. Forty-one pine sawmills supplied both questionnaires and chip samples from their operations, and three pine mills responded with chip samples only. Twenty-four hardwood sawmills returned both the questionnaire and chip samples.

Sawmills cooperating in the study were members of the Southeastern Lumber Manufacturers Association or were chip suppliers of a cooperating pulp mill. Chip samples were collected from various chipping equipment lines associated with the sawmills. All chip samples were transported to Mississippi State University. Chip samples were received during October and December 1990, with most samples arriving in November and early December.

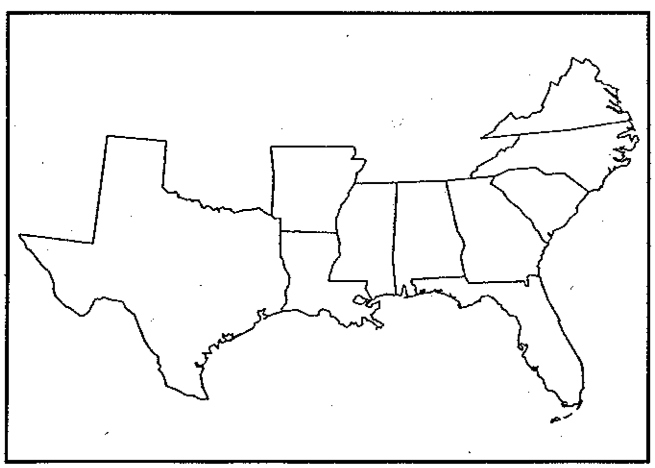


Figure 2. States represented in the sawmill chip quality study.

Chip Classification System

Chip quality, as used in this study, refers to the percentages of *fines, pins, accepts,* and *overs* in each sample. Chip quality was determined using a mechanical classifier provided by Price Services of Monticello, Arkansas. The Price Classifier is a mechanical drum sorter that uses thickness and length measurements to group chips into six possible classifications (Table 1). Bark content of the accepts and overs was determined by hand separating and weighing.

Table 1. Price Classifier chip categories.

Chip Fraction	Chip Thickness	Chip Length
	(mm)	(mm)
Fines	<2	<5
Pins	<2	>5
Accepts[1]	2-8	<45
Accepts	2-8	>45
Overs	>8	<45
Overs	>8	>45

[1]The two categories of accepts and the two categories of overs were combined into an overall accepts and overs category for this analysis.

Data Analysis

One-way analysis of variance techniques using single degree of freedom test were used to examine significances between group means of chip fractions among the various milling processes. Simple linear regression techniques were used to model chip fractions as a function of chipper operating parameters. Chip fraction data are presented in Appendix B.

Pine Sawmills

Lumber and Chip Production

Average total annual lumber production amounted to 38.1 million board feet, mill tally (range from 4.1 to 118.0 MMBF) for those sawmills reporting production data in the study. Average annual chip production amounted to 78,472 green tons (range from 10,000 to 273,000 green tons). As might be expected, mills producing more lumber also produced more chips (Figure 3). Equation 1 demonstrates this rela-

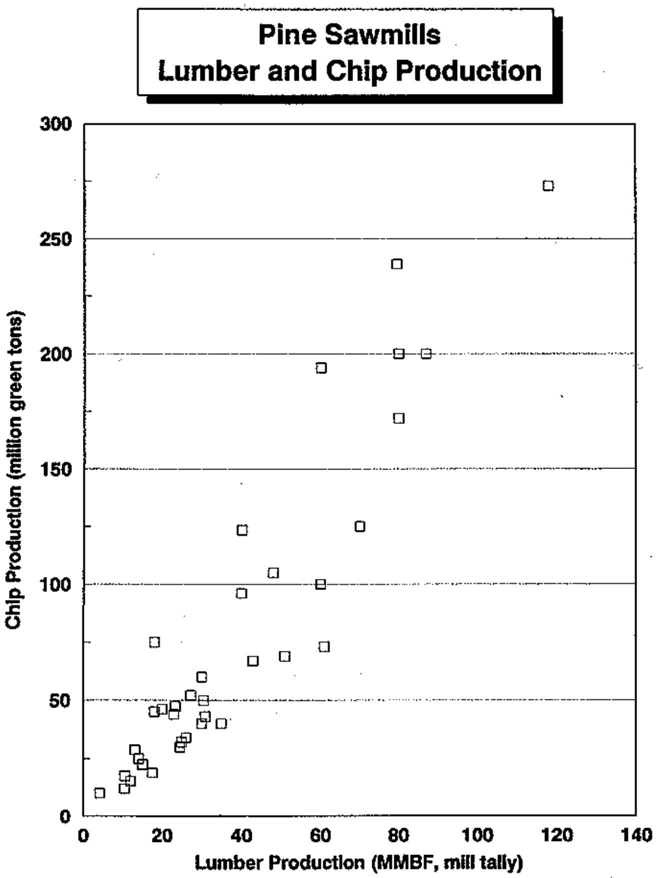


Figure 3. The relationship between chip production and lumber production for pine sawmills.

tionship according to data reported by the participating study sawmills.

PINECHIP = 2,174 LUMTALLY [1]
n = 36 st.dev.= 97.86 p = 0.000

where:
PINECHIP = pine chip production, thousands of green tons
LUMTALLY = pine lumber production, million board feet, mill tally.

The equation indicates that 2.17 tons of chips are produced with the manufacturing of 1,000 board feet (one mbf) of lumber. The chip production figures for this study were for clean chips being sold, used internally, or sent to a landfill.

Koch (1985) reported 2.51 tons of pine chips resulted from the production of one mbf of pine lumber. Differences between the relation of chip and lumber production for this study and the relationship reported by Koch may be because this study's data were for clean (screened) chips and Koch's were for unscreened chips. However, this study's estimates of chip production are greater than those reported by Ellis and Brown (1986) of the Tennessee Valley Authority.

Sawmill Equipment Characteristics

Debarking Systems. Forty-five of the 46 sawmills reported pine sawmill debarking systems were ring-type debarkers. Ring debarkers with a maximum diameter stem capacity of 26- or 30-inches accounted for 74 percent of the reported debarking systems. Reported feed rates for the debarking systems were quite variable, ranging from 25 to 330 feet per minute, averaging 149 feet per minute.

Disc Chippers. Wood chips can be produced at numerous locations within a sawmill operation. Sawmills use disc chippers to produce wood chips from sawmill residues such as log cutoffs, slabs removed when facing logs, edged material from lumber, and lumber trim ends.

Disc chippers of 48, 60, and 66 inches in diameter accounted for 61 percent of all chippers reported by pine sawmills. Disc chippers with six or eight knives accounted for 91 percent of those reported. Sixty-inch disc chippers with six or eight knives were the most common configurations reported by sawmills (Table 2). All but one of the disc chippers in the study used a horizontal feed method rather than a drop feed for supplying material to the chipper. Fifty-six percent of the reported disc chippers used a blowing chip discharge system, and the rest used a bottom chip discharge system.

Sawmill disc chippers operated at a reported average speed of 676 rpm with one chipper reported operating at 1,100 rpm and another at 1,800 rpm. Discounting the two high reported operating speeds as being outside the range of expected operating speeds for disc chippers, the remaining chippers operated at average speed of 633 rpm. Seventy-three percent of the reported chippers were setup for a target chip of ⅝-inch or ¾-inch.

Sawmill Chipping Heads. Sawmills using chipping heads are capable of producing wood chips directly from the log during the milling process. There are

Table 2. Number of various combinations of disc diameter and knife sets in pine sawmill disc chippers.

	Number of Knives				
Disc Diameter	**3**	**4**	**6**	**8**	**16**
(inches)					
48	–	–	6	4	–
54	–	–	2	1	–
58	2	–	5	2	–
60	–	–	10	8	–
64	–	–	3	–	–
66	–	–	3	6	1
72	–	–	–	2	–
75	–	1	4	–	–
84	1	1	–	1	–

several places within the sawmill where chipping heads are utilized. A *chipping headrig* typically uses four chipping heads in its milling process; a top, a bottom, and two side heads. Top and side heads are adjusted according to log diameter for best lumber production. Side chipping heads form flat surfaces on the log, while the top and bottom chipping heads profile the log, which is then directed into circular saws for lumber production. There were 12 chipping headrigs reported operating by the 41 responding sawmills. Reported operating characteristics for the three types of chipping heads are listed in Table 3.

Chipping edgers may use up to three chipping heads to further process slabs or boards into lumber. These heads may include two side heads and a top head; chipping heads are usually similar to those found in chipping headrigs. There were 11 operating chipping edgers as reported by the 41 sawmills.

Slabbing headrigs are located in-line and prior to band and circular headrigs. Slabbing headrigs typically use a six- or eight-knife disc in order to produce flat surfaces on the log before it enters the sawing headrig. *Chipping canters* typically use the same type of chipping head as a headrig slabber in order to produce two- or four-sided cants, which then enter gang saws for the milling of lumber. These two processes were combined as a *slabber/canter* chipping head type in this study. The 41 pine sawmills reported operating 31 slabber/canters in their operations.

Chip Screening. Fines and pin chips lower pulp yields and strengths (as a consequence of over-cooking) and cause liquor circulation problems during chemical pulp cooks. Oversized chips are the main cause of screen rejects in chemical pulping (Smoot and Kocurek, 1989). Thus, chip screening is utilized by sawmills in order to reduce the amount of fines, pins, and oversized chips in their chip supply.

The gyratory screening system is the predominant type of screening system used by sawmills. Eighty-seven percent of the 47 reported screening systems were of the gyratory type, while the remaining 13 percent (6) were vibratory conveyors. Forty-nine percent of the reported gyratory screening systems measured 8 feet by 8 feet or 10 feet by 10 feet.

Gyratory and vibratory conveyor screening systems typically consist of two screen layers. A supply of wood chips is deposited on a gyrating top screen. The purpose of the top screen is to retain oversized chips while allowing fines, pins, and acceptable size chips to fall through. A gyrating bottom screen functions to retain acceptable size chips while allowing smaller fines and pin chips to fall through.

Hole openings for pins and overs for the vibratory conveyor systems were greater than for the gyratory screening systems. The average pins hole size of 0.34 inch for the vibratory systems was significantly higher than the 0.27 inch for gyratory systems ($p < 0.08$). The average overs hole size of 2.21 inches for the vibratory systems was significantly higher than the 1.75 inches for gyratory systems ($p < 0.02$).

Table 3. Reported operating characteristics of chipping heads in pine sawmills.

	Number Reported	Average	Standard Deviation
Operating Speed (rpm)			
Chipping Headrig	7	1,757.1	330.9
Chipping Slabber/Canter	9	791.1	197.1
Chipping Edgers	3	1,866.7	305.5
Feed Rate (feet per minute)			
Chipping Headrig	8	219.6	37.0
Chipping Slabber/Canter	7	214.4	26.4
Chipping Edger	6	412.3	211.8

Chip Quality

Unscreened Chips from Disc Chippers. Chipper discharge method has been shown to affect chip quality in a previous study on roundwood (Twaddle, 1990).

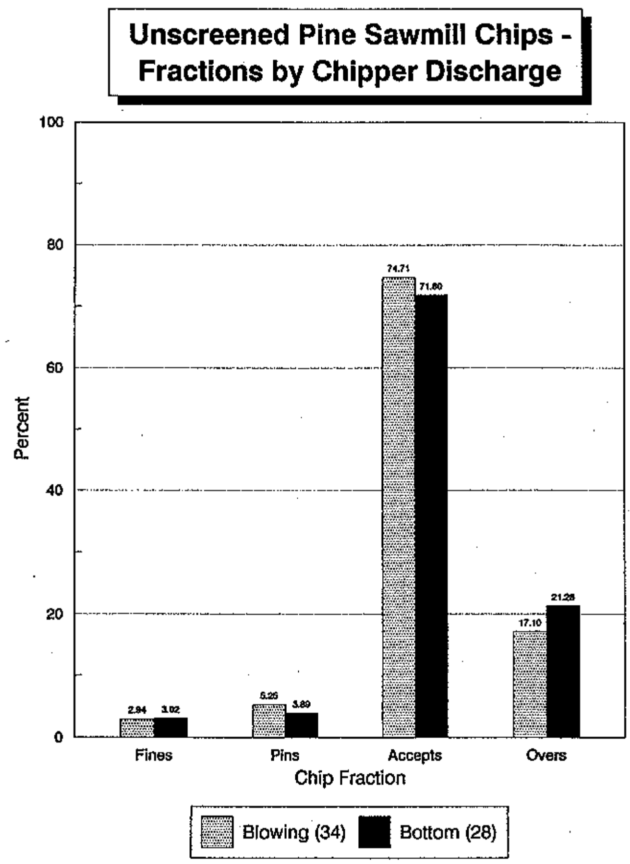


Figure 4. Average unscreened pine chip fractions as affected by blowing and bottom disc chipper discharge systems.

The force of a blowing discharge system degrades wood chips into smaller fines and pin chips. Figure 4 demonstrates the average chip fractions from sawmill disc chippers with blowing and bottom discharge systems. While the fines fractions for both discharge systems were virtually the same, pin chips production was substantially more from blowing discharge chippers (5.3%) than from bottom discharge systems (3.9%) ($p < 0.06$). These results tend to corroborate conclusions drawn for roundwood disc chipper discharge systems and the resulting impact on chip quality (Twaddle, 1990).

Data for bottom and blowing discharge disc chippers were combined in order to explore the effects of type of sawmill residue on chip fractions. The fact that several types of sawmill residues are fed to the chipper simultaneously complicates the examination of the impact of sawmill residue on chip fractions. Consequently, samples contained chips from several sources. Statistical analyses were performed to detect differences in chip fractions for those samples with and without a particular sawmill residue. Results of the analyses are presented in Figure 5.

The only significant difference ($p < 0.05$) occurred with board edgings. Chip samples with board edgings as a residue infeed material had higher levels of accepts (77.5%) and lower levels of oversized chips (14.6%) than samples without board edgings (66.9% and 25.9%). Chip samples without board edgings may have contained a higher proportion of chips from trim blocks and this may have influenced a higher level of oversized chips as chips from trim blocks have been shown to contain higher levels of overs. Additionally, chips from edgings have been shown to have fewer oversized and more accepts than trim block residues (TAPPI, 1989).

Unscreened Chips from Chipping Heads. Chips produced by three types of chipping heads—(a) *chipping headrigs,* (b) *slabbers/canters,* and (c) *chipping edgers*—were analyzed to detect differences in chip distributions. Results of these comparisons are presented in Figure 6.

Chipping headrigs (81.3%) and chipping edgers (81.9%) produced significantly more accepts than slabber/canters (74.6%). Chips from slabber/canters contained significantly more overs (19.2%) than chipping

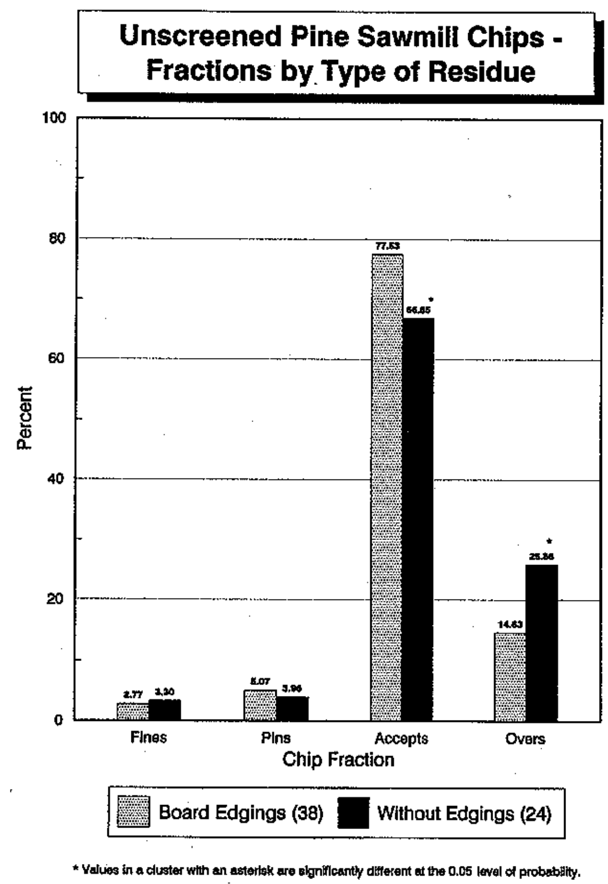


Figure 5. Average unscreened pine chip fractions as affected by type of mill residue.

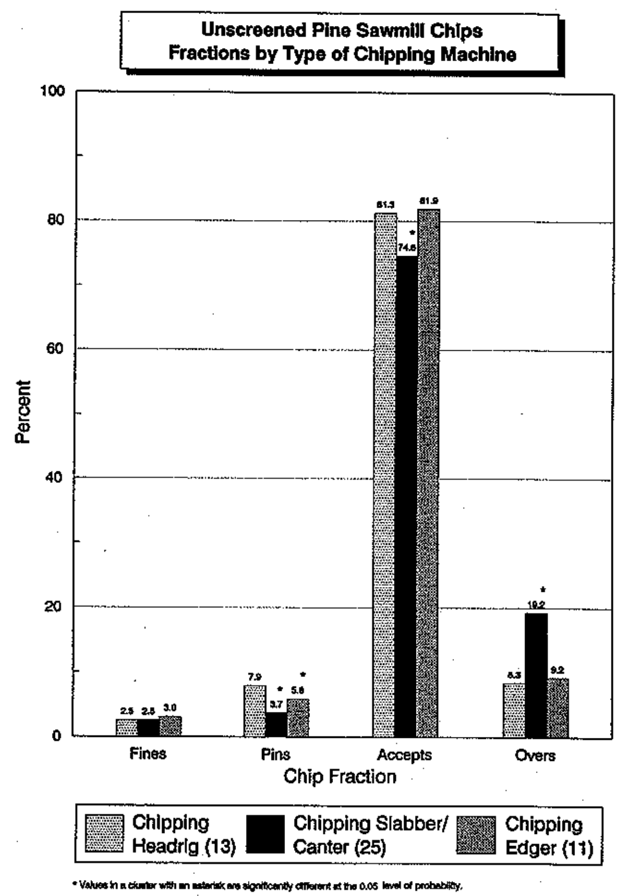


Figure 6. Average unscreened pine chip fractions as affected by chipping headrigs, chipping slabber/canters, and chipping edgers in sawmill chipping machines.

headrigs (8.3%) and chipping edgers (9.2%). Increasing quantities of pin chips occurred in the following order; slabber/canter (3.7%) < chipping edger (5.8%) < chipping headrig (7.9%). Similarities in the chip fractions between chipping headrigs and chipping edgers can be attributed to similar chipping knife design and configurations. The high amount of pins and fines produced by chipping headrigs is thought to result from the lack of a free passage for the chip to discharge, and consequently a substantial amount of chip fragmentation due to the collision between the chips and the chipping head (Galloway and Thomas, 1972).

Sawmill operators can adjust the operating speed of their chipping heads to influence chip size. A faster operating machine should produce smaller chips because more cutting knives are presented to a log over a set distance (assuming feed rates remain constant for logs of a given size). The following equations represent fines, pins, and oversized chip fractions as related to chipping head operating speed. Equation 2 is for slabber/canters, and Equations 3 and 4 are for chipping headrigs and chipping edgers combined.

$$FINES = 0.00353\ RPM \quad [2]$$
$n = 9$ st.dev. $= 0.00071$ $p = 0.000$

$$PINS = 0.00412\ RPM \quad [3]$$
$n = 11$ st.dev. $= 0.00057$ $p = 0.000$

$$OVERS = 38.71 - 0.01701\ RPM \quad [4]$$
$n = 12$ st.dev. $= 0.00934$ $p = 0.102$ $r^2 = 0.27$

Equations 3 and 4 presented here are slightly different than those reported in Dubois, Watson, and Wagner (1991). One observation was dropped from the data set after it was established that the operating characteristics of the chipping head were unique and may impact chip fractions.

Figures 7, 8, and 9 demonstrate the relationship expressed in the three equations. While the sample sizes are admittedly small, the equations do indicate that a sawmill operator can exercise some control over chip size by manipulating the operating speed of the chipping head. Additionally, the results indicate an opportunity to establish the relationship between machine design, operating parameters, and chip characteristics through controlled research studies.

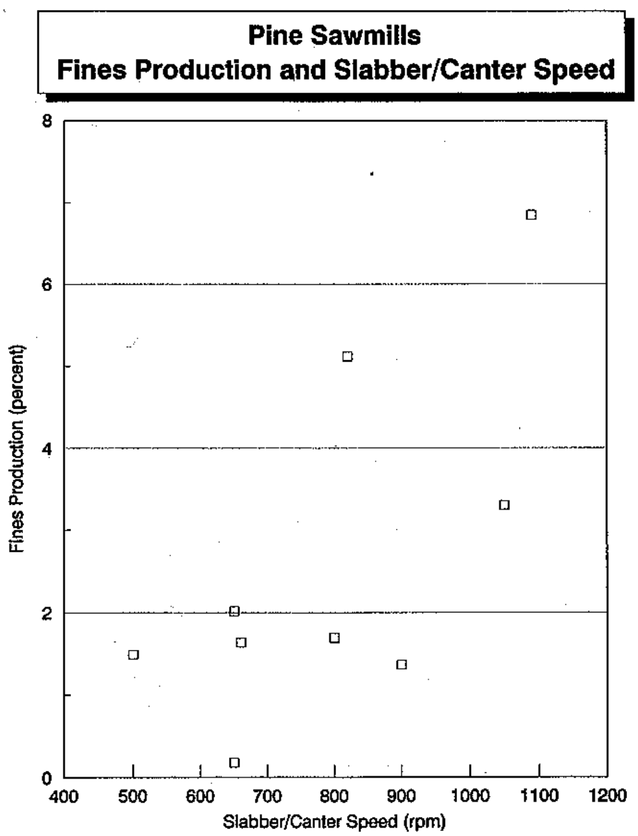


Figure 7. The relationship between fines production in unscreened pine chips and slabber/canter operating speed.

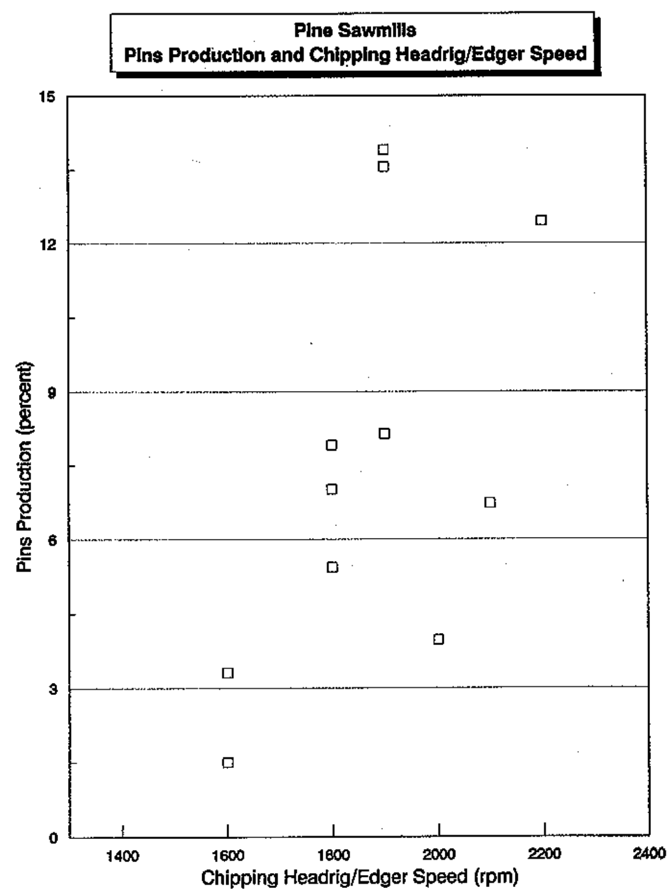


Figure 8. The relationship between pin chips production in unscreened pine chips and chipping headrig/edger operating speed.

Unscreened Chips – Comparing Disc Chippers and Chipping Heads. Unscreened wood chips from disc chippers and sawmill chipping heads were examined to isolate differences in chip fractions between the two chipping processes (Figure 10). The findings indicate that sawmill chipping heads produce significantly more accepts (78.1%) and fewer oversized chips (13.9%) than disc chippers (73.4% and 19.0%). These findings concur with those of Hatton (1975) in his study on sawmill chippers in British Columbia.

Screened Chips. The screened chip samples resulting exclusively from sawmill disc chippers were examined to investigate the impact of chipper discharge method on chip fractions. Figure 11 indicates a significant difference in pin chips occurs between the two discharge systems, with blowing discharge chippers producing approximately twice the percentage of pin chips (5.6%) as bottom discharge chippers (2.9%).

Blowing discharge systems produced more pin chips in unscreened chip fractions compared to bottom discharge systems, and this relationship carried over to the screened chip fractions. Pin chip fractions for bottom discharge systems are reduced from 3.9 percent of the total before screening to 2.9 percent of the total after screening. However, pin chip fractions for blowing discharge systems increased from 5.3 percent of the total before screening to 5.6 percent of the total after screening. The failure of blowing discharge system to realize a reduction of pin chip fractions after screening compared to before screening may result from inefficient screening. Chip screening systems associated with blowing discharge systems may need to be larger so that a flow of chips are retained on the screens longer allowing for increased opportunity for fines and pins removals.

Hardwood Sawmills

Lumber and Chip Production

Average total annual lumber production amounted to 7.6 million board feet, mill tally (range from 2.1 to 18.0 MMBF), for those hardwood sawmills reporting production data in the study. Average annual chip production amounted to 9,976 green tons (range from 3,600-17,850 green tons). Equation 5 demonstrates

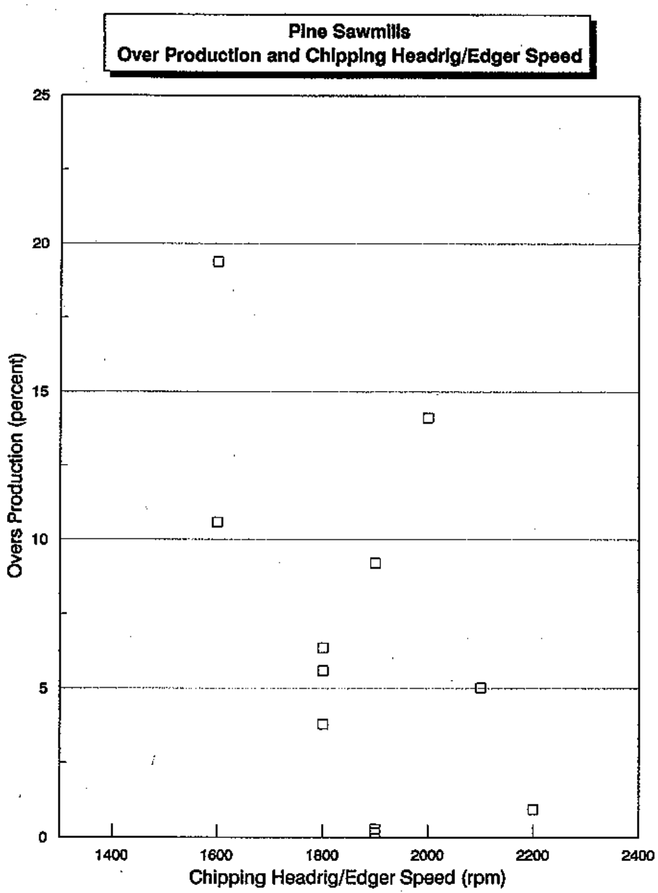
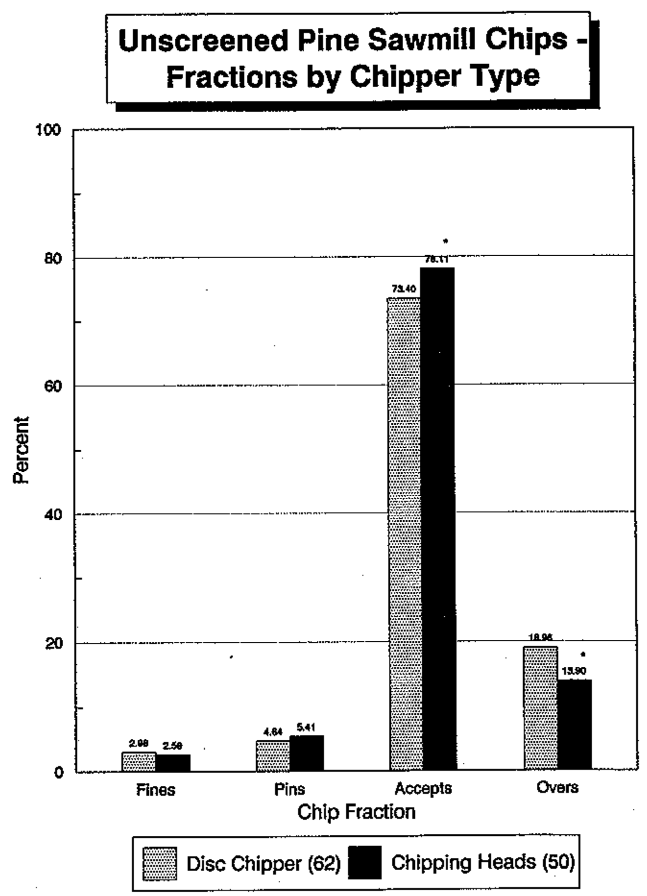


Figure 9. The relationship between oversized chip production in unscreened pine chips and chipping headrig/edger operating speed.



* Values in a cluster with an asterisk are significantly different at the 0.05 level of probability.

Figure 10. Comparison of average unscreened pine chip fractions between disc chippers and sawmill chipping machines.

the relationship between hardwood chip production and hardwood lumber production according to data reported by the participating study sawmills (Figure 12).

$$\text{HARDCHIP} = 3{,}482 + 0.802\ \text{LUMTALLY} \qquad [5]$$

$n = 18$ st.dev.= 124.2 $p = 0.000$ $r^2 = 0.72$

where:
HARDPROD = hardwood chip production, thousands of green tons
LUMTALLY = hardwood lumber production, million board feet, mill tally.

Equation 5 presented here is different than a similar equation presented in Dubois, Watson, and Wagner (1991). One observation was dropped from the data set after it was established that the type of logs received at the mill may impact the relationship between lumber and chip production.

Koch (1985) reported an estimating factor of 1.49 tons of hardwood chips per mbf of hardwood lumber production. Koch's factor is lower than the 0.802 tons per mbf determined by this study. Differences between the relation of chip and lumber production for this study and the relationship reported by Koch may be because this study's data was for clean (screened) chips and Koch's were for unscreened chips.

Sawmill Equipment Characteristics

Debarking Systems. Seventeen of the 22 reported debarking systems were rosser-type debarkers and five were ring-type systems. Rosser debarkers with the maximum diameter stem capacity of 30 and 36 inches accounted for 45 percent of the hardwood debarking systems. Because of insufficient survey response information, debarker feed rates are not presented for hardwood mills.

Disc Chippers. Hardwood sawmills typically do not use chipping heads to produce wood chips directly from hardwood logs. Rather, they rely on disc chippers to produce wood chips from sawmill residues, such as log cut-offs, slabs removed when facing logs, edged material from lumber, and lumber trim ends.

One-third of the reported disc chippers were 60 inches in diameter. Disc chippers with six knives accounted for 77 percent of the chippers reported. The

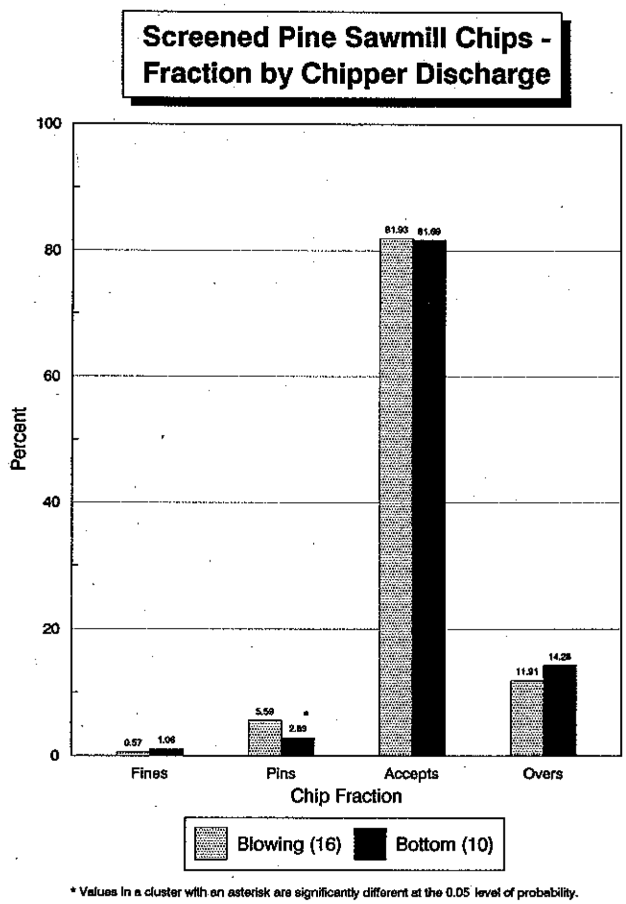


Figure 11. Average screened pine chip fractions as affected by blowing and bottom disc chipper discharge systems.

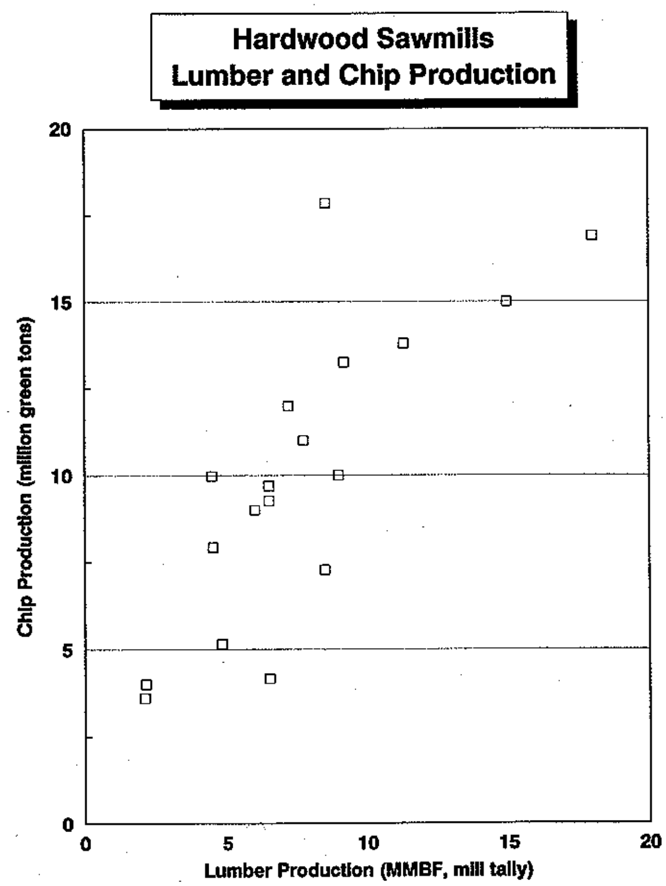


Figure 12. The relationship between chip production and lumber production for hardwood sawmills.

reported knife/diameter configurations used by those sawmills reporting disc chipper information are found in Table 4. All disc chippers in the study utilized a horizontal feed method to supply material to the chipper. Two-thirds of the reported disc chippers used a blowing chip discharge system, and one-third used bottom chip discharge systems.

Hardwood sawmill disc chippers operated at a reported average speed of 780 rpm with two chippers reported operating at 1,800 rpm. Discounting the two high-speed chippers, the remaining chippers operated at average speed of 660 rpm. Two-thirds of the reported disc chippers were set up to produce either a ⅝- or ¾-inch length chip.

Chip Screening. The gyratory screening system predominates those used by hardwood sawmills. Twenty-two of the 23 screening systems reported were of gyratory type. Fifty-nine percent of the reported gyratory screening systems measured 6 by 6, or 7 by 7 feet. Hole size for screening oversized chips averaged 1.64 inches and pin hole size averaged 0.28 inch for the reported hardwood sawmill screening systems.

Chip Quality

Unscreened Chips. As with pine sawmills, chipper discharge method has been shown to affect chip quality in a previous study on roundwood (Twaddle, 1990). The force of a blowing discharge system degrades wood chips into smaller fines and pin chips. Figure 13 demonstrates average chip fractions for blowing and bottom discharge systems for hardwood sawmill disc chippers.

A previous roundwood study has demonstrated greater fines and pins production associated with blowing discharge systems (Twaddle, 1990). Fines and pin chip fractions were lower for bottom discharge systems (1.9% and 3.2%) than for blowing discharge systems (2.9% and 4.5%) for hardwood sawmill disc chippers, however, differences were not significant. The variability in the chip samples and the relatively few number of samples may disguise statistical differences between the two discharge systems.

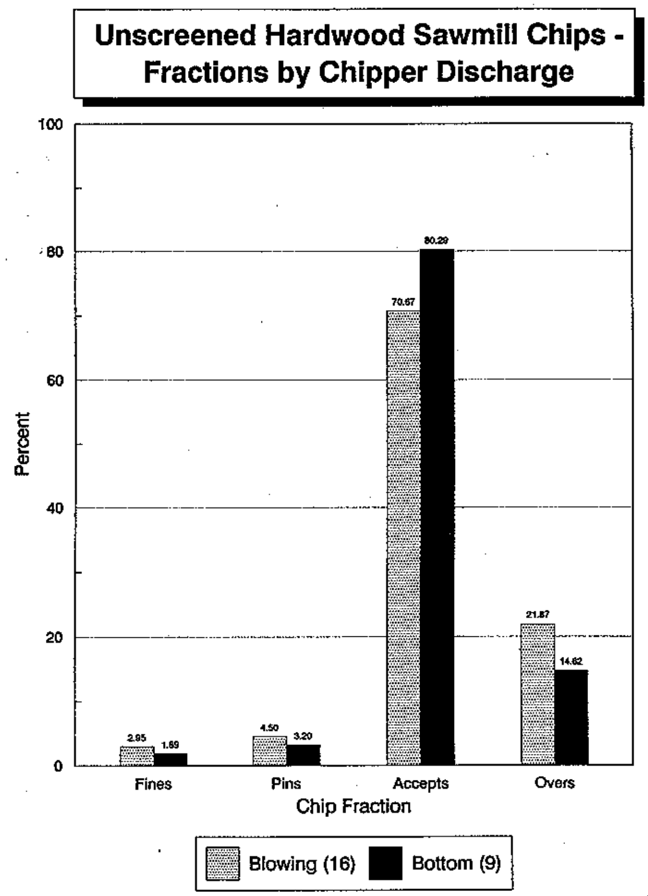


Figure 13. Average unscreened hardwood chip fractions as affected by blowing and bottom chipper discharge systems.

Examination of the impact on chip fractions by type of sawmill residue entering the disc chipper was made difficult because several types of sawmill residues are fed to the chipper simultaneously. Thus, samples contained chips from several sources. Statistical analyses were performed to detect differences in chip fractions from samples with and without a particular sawmill residue. The small number of samples hampers and qualifies any statistical conclusions. Results of the analysis are presented in Figure 14.

The only significant difference occurred with slabs. Chip samples with slabs as a residue in-feed material had lower levels of oversized chips (16.1%) than samples without slabs (32.1%). Chipping slabs and edgings have been shown to produce fewer oversized chips than other sawmill residues and these results corroborate previous studies as well as the pine data reported earlier in this paper (TAPPI, 1989).

Table 4. Number of various combinations of disc diameter and knife sets in hardwood sawmill residue disc chippers.

Disc Diameter	Number of Knives 3	4	6	8
(inches)				
48	1	–	1	2
54	–	–	4	–
58	1	–	2	–
60	–	–	8	1
64	–	–	2	–
66	–	–	1	–
70	–	–	3	–
75	–	1	–	–

Screened Chips. Statistical analyses were performed to detect differences in screened hardwood chip fractions from samples with and without a particular sawmill residue. Results of the analyses are presented in Figure 15.

Chip samples with slabs as a residue in-feed material had lower levels of fines (0.58%) and greater amounts of accept chips (82.7%) than samples without slabs (1.6% and 74.0%). Chip samples with board edgings had lower levels of fines and pin chips (0.58% and 2.5%) than samples without edgings (1.5% and 5.4%).

Screened hardwood chip samples resulting from sawmill disc chippers were examined to investigate the impact of chipper discharge method on chip fractions. There were no significant differences in chips fractions between the two discharge sytems (Figure 16). Although a 5 percent difference in the acceptable chip fraction was detected between the two discharge methods, the variability of the chip fractions and relatively low number of samples may have masked statistical differences.

Chip Quality by Production Source

Earlier studies conducted by the Forestry Department at Mississippi State University concentrated on chip quality produced from two sources: woodland chippers, and woodyard and satellite mills. The recent data on sawmills' residual chips enables a comparison of chip quality produced from all three sources.

Data Collection

In two previous studies (Twaddle, 1990; Watson et al., 1991), chip samples were collected throughout 12 southern states from Virginia to Texas. Similar questionnaires were used to collect information about the operating characteristics of woodyards and sawmills willing to cooperate in the chip study. Mills participating in the woodyard study were identified from Lockwood Post's Directory. Woodland chips were collected only from Oklahoma, Arkansas, and Mississippi.

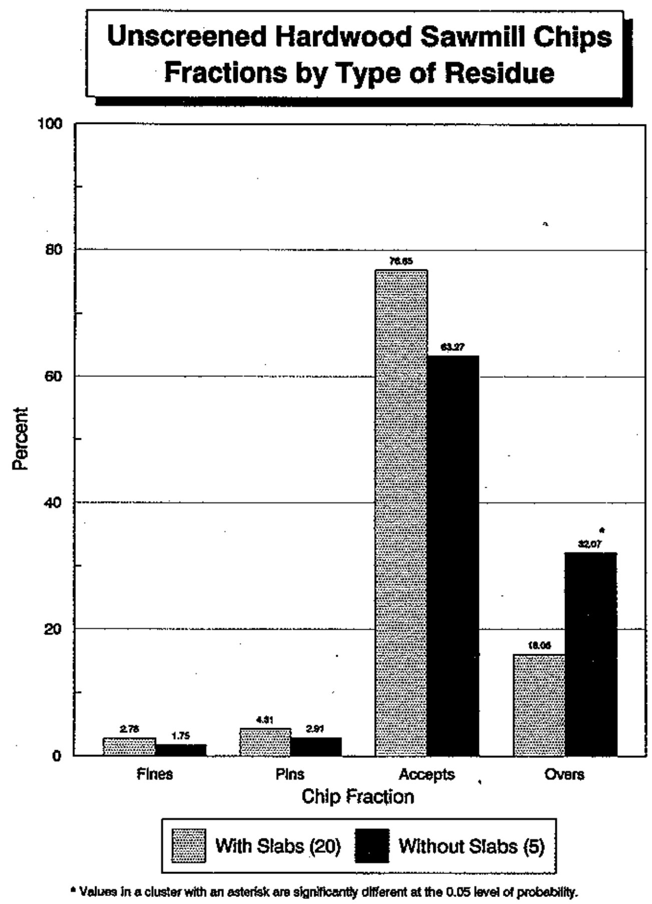


Figure 14. Average unscreened hardwood chip fractions as affected by type of mill residue.

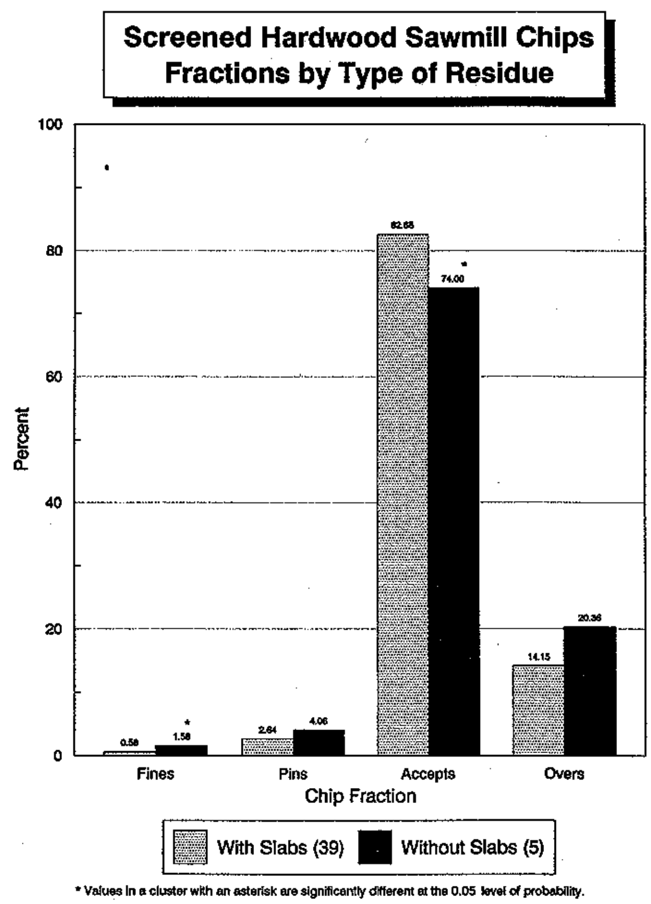


Figure 15. Average screened hardwood chip fractions as affected by type of mill residue.

Unscreened pine chips were collected at all three production sources, while screened pine chips, unscreened hardwood chips, and screened hardwood chips were only collected at woodyard and sawmill sites. Data from the two previous studies were combined with the sawmill study into one data set.

Chip Sources

Woodland Chips. An "in-woods" chipping operation normally consists of feller-bunchers, grapple skidders, a knuckleboom loader, a chain flail, a woodland chipper, and several chip vans. At the deck or landing, tree-length softwood stems with limbs and tops still intact are fed into a chain flail using a knuckleboom loader. Chain flails have two drums designed to hold 36-39 chains in six rows around the drum. The flails, rotating at about 500 rpm, remove the limbs and bark. After exiting the flail debarker, the tree-length stems enter the chipper.

Chippers in this study were diesel-powered disc chippers capable of handling stems having diameters up to 23 inches. All the chippers were equipped with separators. To complete the operation, chips are blown into waiting chip vans. Chip samples used in this analysis were collected from 12 woodland chipping operations in the fall of 1989.

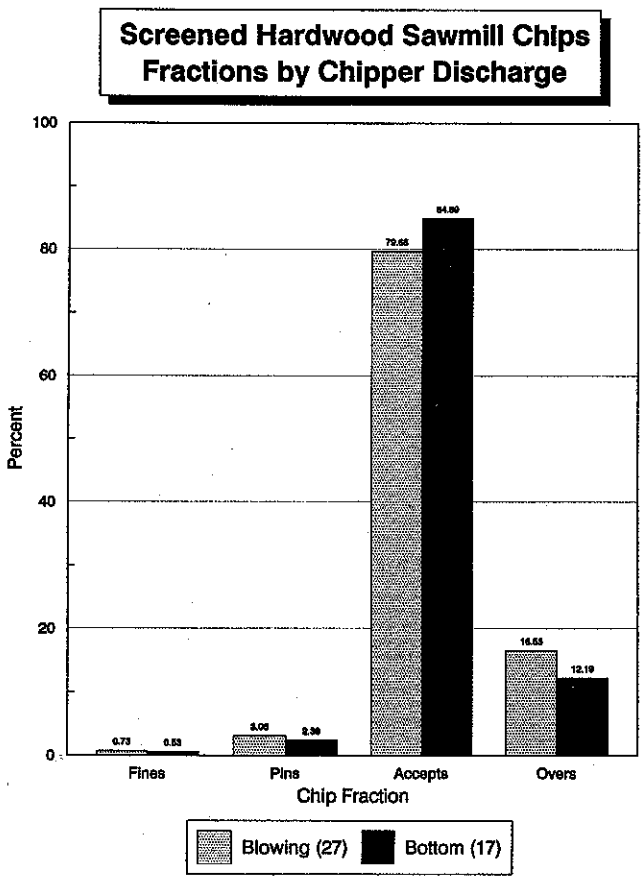


Figure 16. Average screened hardwood chip fractions as affected by blowing and bottom disc chipper discharge systems.

Woodyard Chips. In this study, woodyard chips include wood chips produced by satellite mills and mill yard facilities at pulp mills. Chip samples were collected at 50 of the estimated 77 pulp mills, and from 21 satellite yards of the estimated 84 locations that produce at least 100,000 tons of chips per year (Twaddle, 1990).

Satellite mills typically receive tree-length material and use horizontal feed systems. Mill yard facilities receive tree-length, random length, and shortwood material and use horizontal or drop feed systems. Both systems use disc chippers and drum debarkers. Chips produced from satellite mills must be transported to the pulp mill, while chips from mill yard facilities are normally blown or augured to the mill's inventory pile. Chip samples used in this analysis wre collected from 71 woodyard operations in the fall of 1989.

Sawmill Chips. The dissertation preceding this section provides a detailed accounting for chip production processes in sawmills. Chip samples used in this analysis include those collected from sawmills in the fall of 1990. The same chip classification and data analysis techniques were used in this section as were conducted for the pine and hardwood sections. Readers are referred to previous sections for a description of the chip classification system and data analysis.

Chip Quality by Production Sources

Unscreened Pine Chips. The statistical results of analyzing unscreened pine chips are summarized in Figure 17. Unscreened pine chips produced from woodlands had the highest percentage of overs (29.0%) and the lowest percentage of accepts (68.0%) and pins (1.8%). Woodlands produced nearly 150 percent more overs and about 10 percent fewer accepts than woodyards or sawmills. Woodland chippers usually have lower horsepower motors, operate at a higher rpm, and are thought be more poorly maintained than woodyard chippers. These and others factors could account for the higher percentages of overs from woodland operations. However, most of the overs will be recovered after screening and rechipping.

There were no significant differences in the percentages of overs, accepts, or bark produced in woodyards and sawmills. However, unscreened pine chips from sawmills were higher for pins (5.4%) and fines (3.2%). Sawmills produced almost three times more pins than woodland operations. This can be attributed to the sawing process used in the production of lumber in sawmills and the freshness of the wood in woodland operations.

Screened Pine Chips. Screening pine chips reduced the amount of overs by about 3 percent, increased accepts by approximately 5 percent, decreased pins by about 0.5 percent, and decreased fines by about 1.5 percent for both woodyard and sawmilling operations (Figure 18). After screening, woodyards produced more overs (16.9%) than sawmills (12.9%). This difference can probably be attributed to the physical attributes of the oversized chips. Sawmills produce an abundance of grossly oversized chips from lumber trim blocks. Screening systems should be more efficient in removing those overs compared to the marginal overs more typically produced by woodyard chippers.

Sawmills produced more pins (4.7%) than woodyards (3.2%), attributable to the sawmilling process. No significant differences in accepts and bark fractions were detected between woodyard and sawmill processes. Bark content was approximately one percent for both operations.

Unscreened Hardwood Chips. Unscreened hardwood chips from sawmills had higher percentages of pins (3.9%) and fines (2.5%), but were not significantly different from woodyards in the percentage of overs and accepts that were produced. Sawmills produced about twice as many pins and fines as woodyards because of the sawmilling process (Figure 19).

Screened Hardwood Chips. The statistical results for screened hardwood chips are shown in Figure 20. Screening hardwood chips reduced the amount of overs by about 4.5 percent, increased accepts by about 6 percent, increased pins by about 1 percent and decreased fines by approximately 1 percent. After screening, there were no significant differences between woodyards and sawmills for overs, accepts, pins, or fines. Bark content, however, was significantly higher in woodyard samples (2.6%) compared to those from sawmills (0.75%). Differences in bark content may be attributed to the species mix. Oak, poplar, and sweetgum dominate the species mix used by sawmills, while woodyard operations use a more diverse mixture of species, including some that are more difficult to debark.

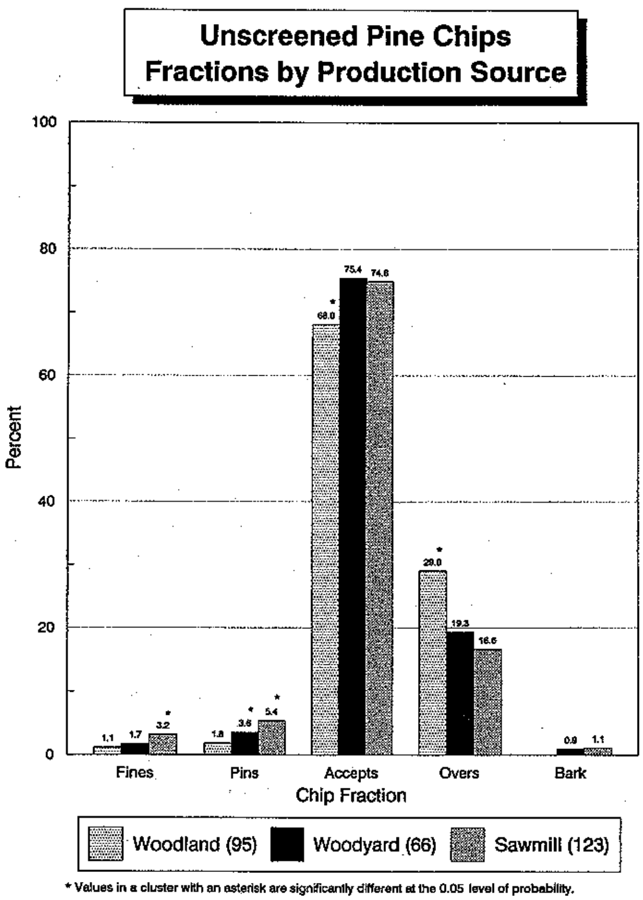


Figure 17. A comparison of unscreened pine chip fractions from woodland, woodyard, and sawmill production sources.

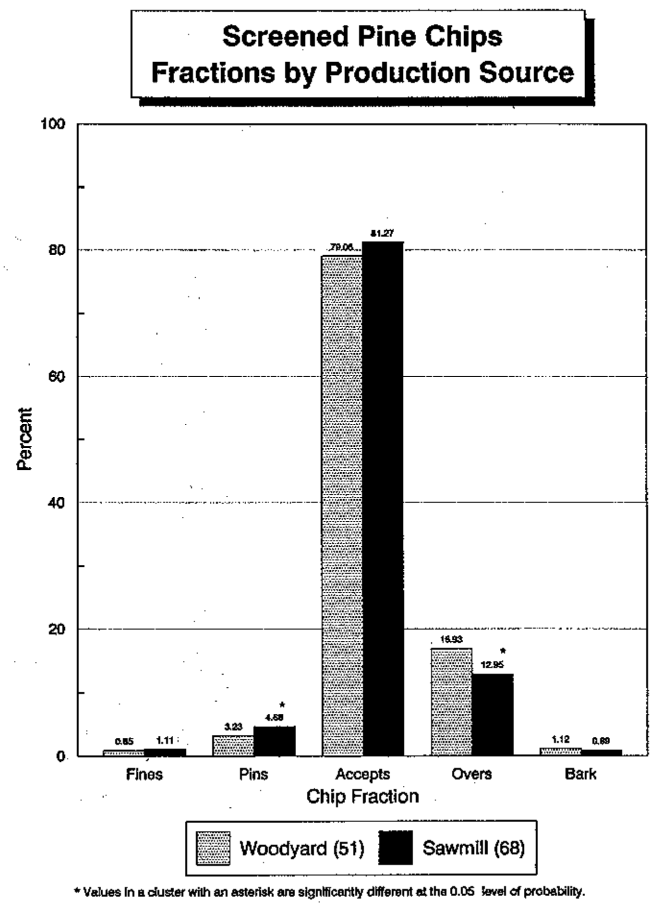


Figure 18. A comparison of screened pine chip fractions from woodyard and sawmill production sources.

Summary and Conclusions

The appropriateness of sawmill chips from the U.S. South as a pulping fiber supply has not been addressed or debated within this research endeavor. Different pulping methods have different chip size requirements. An average thickness of 2-4 mm is the preferred chip dimension for the kraft pulping process (Hartler and Strade, 1979). Continuous digester systems are an integral component of the U.S. South's pulp industry and these types of systems are more sensitive to the smaller chip fractions than are batch digesters. However, a common thread in preferred chip dimensions among the pulping methods is the minimization of fines and oversized chip fractions in a fiber supply.

Study results for pine wood chips from different production systems are similar to those reported by Hatton (1976) for softwood species in British Columbia. He found that sawmills produced more pin and fine chips and fewer oversized chips compared to roundwood disc chippers in woodyards. Hatton also reported that the average thickness of the acceptable chip fraction (2-8 mm) was lower for sawmill chips than roundwood disc chippers.

Detailed measurements of the acceptable chip fraction were not available in this study because the Price Classifier does not segregate chip fractions in the 2-8 mm range. However, since pine sawmill chips had a higher pins and fines content and a lower oversize content compared to woodyard chips, it is quite likely that the average thickness for the acceptable fraction of chips would be lower for sawmills than for woodyards.

Hatton's study also demonstrated that screened-pulp yields for kraft pulping in a batch digesting system were maximized for the 2- to 4-mm-thick chip fraction. Therefore, the thinner sawmill chips pulped more uniformly and gave higher screened-pulp yields compared to roundwood. Sawmill chips, however, had lower packing densities than woodyard chips and the author suggested that kraft pulping could be optimized by blending sawmill and woodyard chips.

Whether similar conclusions to Hatton's (1976) can

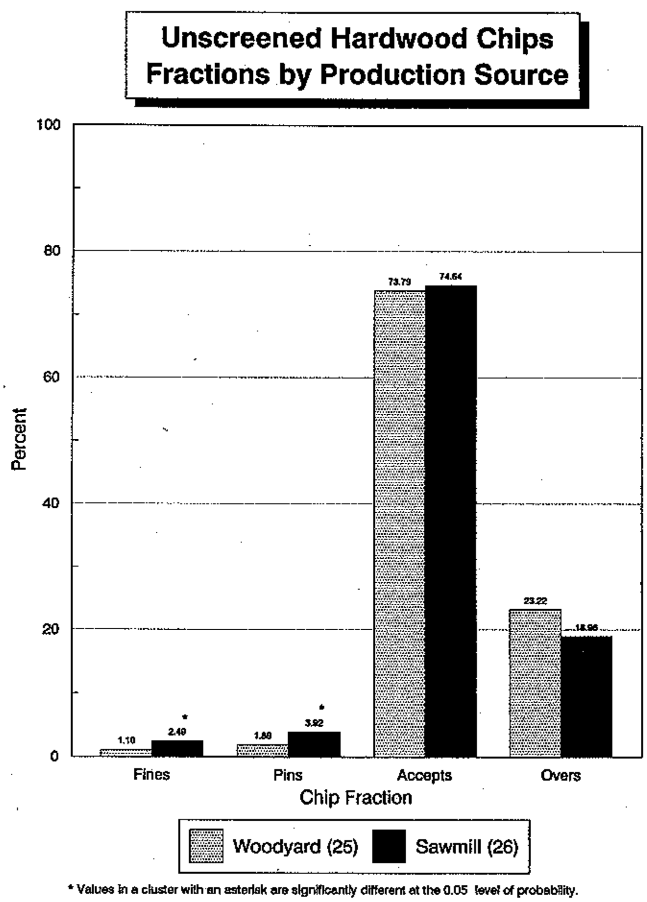


Figure 19. A comparison of unscreened hardwood chip fractions from woodyard and sawmill production sources.

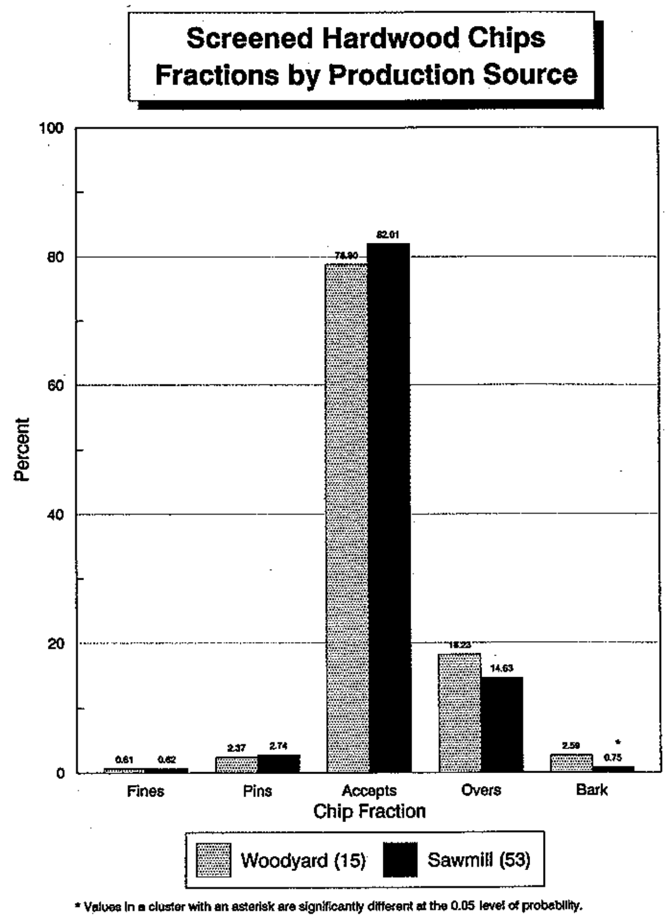


Figure 20. A comparison of screened hardwood chip fractions from woodyard and sawmill production sources.

be drawn for the U.S. South is problematical since no pulping tests were performed in this study. The study results for the U.S. South indicate that sawmill wood chips may be of comparable quality to woodyard chips using chip size distribution and bark content for quality criteria. However, there are other chip characteristics not measured by a chip classifier that may affect pulping efficiency. One of these characteristics is overall chip geometry.

Future analyses and comparisons of sawmill and woodyard chips in the U.S. South should include detailed physical measurements to quantify and establish differences between chip production processes. Since different pulping methods have different chip requirements, more detailed measurements would be useful in evaluating any chipping system on the basis of a particular pulping method.

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Appendix A

SAWMILL CHIP PRODUCTION SURVEY

Mississippi State University
Department of Forestry
Mark Dubois (601) 325-2790

Thank you for taking the time to complete this survey form. We expect that it will take about 15 minutes to answer all of the questions.

Many answers require only a check ✓ in the appropriate block while other answers require volumes, capacities, or percentages. We do not expect you to give exact answers to the last board foot or ton but rather to give us your best estimate.

We have left several places for comment on the form. Please add any additional information that you may feel is necessary for us to interpret your replies correctly.

Mill Code: ____________

ANNUAL WOOD CONSUMPTION

(Give figures for the period July 1, 1989, to June 30, 1990)

Softwood

Roundwood Consumed: ______________ (Give volume)

Unit: (Check one)

Tons ☐ *Cords* ☐

MBF: *Doyle* ☐ *Scribner* ☐ *International* ☐

Other (list) ______________

Species: (check any species making up more than 25% of consumed)

Loblolly ☐ *Slash* ☐ *Longleaf* ☐ *Shortleaf* ☐

Other (list) ______________

Minimum Small-End Diameter of Roundwood Accepted: ______ *inches*

Estimate of Average Small-End Diameter of Roundwood Received: ______ *inches*

Length of Roundwood Received: ______*% Treelength* ______*% Cut to Length Logs*

Hardwood

Roundwood Consumed: ______________ (Give volume)

Unit: (Check one)

Tons ☐ *Cords* ☐

MBF: *Doyle* ☐ *Scribner* ☐ *International* ☐

Other (list) ______________

Species: (Check any species making up more than 25% of consumed)

Oak ☐ *Hickory* ☐ *Elm* ☐ *Ash* ☐ *Gum* ☐ *Cypress* ☐

Other (list) ______________

Minimum Small-End Diameter of Roundwood Accepted: ______ *inches*

Average Small-End Diameter of Roundwood Received: ______ *inches*

Length of Roundwood Received: ______*% Tree Length* ______*% Cut to Length Logs*

Comments: ______________

ANNUAL LUMBER PRODUCTION

(Give figures for July 1, 1989, to June 30, 1990)

Softwood Lumber ________________ *mbf (mill tally)*

Hardwood Lumber ________________ *mbf (mill tally)*

ANNUAL CLEAN CHIP PRODUCTION

(Give figures for July 1, 1989, to June 30, 1990, for total production including clean chips sold, used internally, or sent to a landfill.)

Softwood Chips ________________ *green tons*

Hardwood Chips ________________ *green tons*

EQUIPMENT

Debarkers	Make & Model	Maximum Capacity (stem size)	Lineal Feed Rate
Ring	________	________	________
Rosser Head	________	________	________
Others	________	________	________

Cut Off Saw

Do you have a separate chipper for lily pads & tops? *Yes* ☐ *No* ☐

(Report information for this chipper in chipper section found later in the survey.)

Headrigs	Make & Model	Small-End Diameter		% of Total Lumber Production Accounted For By This Headrig	With A Chipping Slabber?	Make & Model of Chipping Slabber	% of Total Clean Chip Production Accounted For By This Process	Chip Sampling Number
		Minimum	Maximum					
Band(s)	*1.* ______	______	______	______%	*Yes* ☐ *No* ☐	______	______%	______
	2. ______	______	______	______%	*Yes* ☐ *No* ☐	______	______%	______
	3. ______	______	______	______%	*Yes* ☐ *No* ☐	______	______%	______
Circle(s)	*1.* ______	______	______	______%	*Yes* ☐ *No* ☐	______	______%	______
	2. ______	______	______	______%	*Yes* ☐ *No* ☐	______	______%	______
	3. ______	______	______	______%	*Yes* ☐ *No* ☐	______	______%	______
Chipping	*1.* ______	______	______	______%			______%	______
	2. ______	______	______	______%			______%	______
	3. ______	______	______	______%			______%	______

Resaw

	Make & Model	With A Chipping Head? (Yes or No)	% of Total Clean Chip Production Accounted For By This Process	Chip Sample Number
1.	______	*Yes* ▒ *No* ▒	______%	______
2.	______	*Yes* ▒ *No* ▒	______%	______
3.	______	*Yes* ▒ *No* ▒	______%	______

Edger

Type	Number	Make(s) & Model(s)	% of Total Clean Chip Production Accounted For By This Process	Chip Sample Number
Saw	______	______		
Chipping		*1.* ______	______%	______
		2. ______	______%	______
		3. ______	______%	______

Disc Chippers

First Disc Chipper

Chip Sample Number: ______

By-Products Chipped: (Check all that apply) *Lily Pads* ▒ *Tops (cut-offs)* ▒ *Slabs* ▒ *Edgings* ▒ *Lumber (trimmings)* ▒ *Other (list)* ______

Make & Model: ______

Chipper Type (check one): *Disc* ▒ *Drum* ▒

Disc Diameter (inches, check one): *48* ▒ *60* ▒ *72* ▒ *84* ▒ *96* ▒ *104* ▒ *112* ▒ *116* ▒ *120* ▒ *Other* ______

Number of Knives (check one): *4* ▒ *6* ▒ *8* ▒ *10* ▒ *12* ▒ *15* ▒

Feed Method (check one): *Horizontal* ▒ *Drop* ▒

Chipper Discharge (check one): *Bottom* ▒ *Blowing* ▒

Normal Chipper r.p.m.: ______ r.p.m.

Chip Set-Up Length: ______ inches

Percentage of Total Clean Chip Production Accounted for By This Chipper: ______%

Second Disc Chipper

Chip Sample Number: ______________

By-Products Chipped: *Lily Pads* ☐ *Tops (cut-offs)* ☐ *Slabs* ☐ *Edgings* ☐
(Check all that apply) *Lumber (trimmings)* ☐ *Other (list)* ______________________

Make & Model: ______________________________

Chipper Type (check one): *Disc* ☐ *Drum* ☐

Disc Diameter (inches, check one): *48* ☐ *60* ☐ *72* ☐ *84* ☐ *96* ☐ *104* ☐
112 ☐ *116* ☐ *120* ☐ *Other* ______________________

Number of Knives (check one): *4* ☐ *6* ☐ *8* ☐ *10* ☐ *12* ☐ *15* ☐

Feed Method (check one): *Horizontal* ☐ *Drop* ☐

Chipper Discharge (check one): *Bottom* ☐ *Blowing* ☐

Normal Chipper r.p.m.: __________ r.p.m.

Chip Set-Up Length: __________ inches

Percentage of Total Clean Chip Production Accounted for By This Chipper: __________%

Third Disc Chipper

Chip Sample Number: ______________

By-Products Chipped: *Lily Pads* ☐ *Tops (cut-offs)* ☐ *Slabs* ☐ *Edgings* ☐
(Check all that apply) *Lumber (trimmings)* ☐ *Other (list)* ______________________

Make & Model: ______________________________

Chipper Type (check one): *Disc* ☐ *Drum* ☐

Disc Diameter (inches, check one): *48* ☐ *60* ☐ *72* ☐ *84* ☐ *96* ☐ *104* ☐
112 ☐ *116* ☐ *120* ☐ *Other* ______________________

Number of Knives (check one): *4* ☐ *6* ☐ *8* ☐ *10* ☐ *12* ☐ *15* ☐

Feed Method (check one): *Horizontal* ☐ *Drop* ☐

Chipper Discharge (check one): *Bottom* ☐ *Blowing* ☐

Normal Chipper r.p.m.: __________ r.p.m.

Chip Set-Up Length: __________ inches

Percentage of Total Clean Chip Production Accounted for By This Chipper: __________%

Fourth Disc Chipper

Chip Sample Number: ____________

By-Products Chipped: *Lily Pads* ▒ *Tops (cut-offs)* ▒ *Slabs* ▒ *Edgings* ▒
(Check all that apply) *Lumber (trimmings)* ▒ *Other (list)* ____________________

Make & Model: ________________________

Chipper Type (check one): *Disc* ▒ *Drum* ▒

Disc Diameter (inches, check one): *48* ▒ *60* ▒ *72* ▒ *84* ▒ *96* ▒ *104* ▒
112 ▒ *116* ▒ *120* ▒ *Other* ________________

Number of Knives (check one): *4* ▒ *6* ▒ *8* ▒ *10* ▒ *12* ▒ *15* ▒

Feed Method (check one): *Horizontal* ▒ *Drop* ▒

Chipper Discharge (check one): *Bottom* ▒ *Blowing* ▒

Normal Chipper r.p.m.: ________ r.p.m.

Chip Set-Up Length: ________ inches

Percentage of Total Clean Chip Production Accounted for By This Chipper: ________%

Screening

Screen 1 No Chip Screening on Site ▒

Chip Sampling Number: ____________

Manufacturer: ____________

Screens for: *Overs* ▒ *Pins* ▒ *Fines* ▒
(Check all appropriate)

Size Limits: *Overs Minimum* __________ *Pins Maximum* __________
(hole sizes)

Hole Shape: Overs: *Round* ▒ *Square* ▒ *Rectangular* ▒
(Check one) Pins: *Round* ▒ *Square* ▒ *Mesh* ▒

Type Screen: *Flat Gyrator* ▒ *Drum* ▒ *Disc* ▒ *Other* ____________
(Check one)

Screen Unit Dimensions: ________ *x* ________

Thickness Screen Size: *None* ▒ *8 mm* ▒ *9 mm* ▒ *10 mm* ▒
(Check one) *Other* ______________

Screen 2 No Chip Screening on Site ☐

Chip Sampling Number: ______________

Manufacturer: ______________

Screens for: *Overs* ☐ *Pins* ☐ *Fines* ☐
(Check all appropriate)

Size Limits: *Overs Minimum* ___________ *Pins Maximum* ___________
(hole sizes)

Hole Shape: Overs: *Round* ☐ *Square* ☐ *Rectangular* ☐
(Check one) Pins: *Round* ☐ *Square* ☐ *Mesh* ☐

Type Screen: *Flat Gyrator* ☐ *Drum* ☐ *Disc* ☐ *Other* ______________
(Check one)

Screen Unit Dimensions: _________ *x* _________

Thickness Screen Size: *None* ☐ *8 mm* ☐ *9 mm* ☐ *10 mm* ☐
(Check one) *Other* ________________

Screen 3 No Chip Screening on Site ☐

Chip Sampling Number: ______________

Manufacturer: ______________

Screens for: *Overs* ☐ *Pins* ☐ *Fines* ☐
(Check all appropriate)

Size Limits: *Overs Minimum* ___________ *Pins Maximum* ___________
(hole sizes)

Hole Shape: Overs: *Round* ☐ *Square* ☐ *Rectangular* ☐
(Check one) Pins: *Round* ☐ *Square* ☐ *Mesh* ☐

Type Screen: *Flat Gyrator* ☐ *Drum* ☐ *Disc* ☐ *Other* ______________
(Check one)

Screen Unit Dimensions: _________ *x* _________

Thickness Screen Size: *None* ☐ *8 mm* ☐ *9 mm* ☐ *10 mm* ☐
(Check one) *Other* ________________

Oversize Chip Reduction

(Equipment used to handle oversized chips from screens)

Rechipper ☐

Hogger ☐

Shredder ☐

Make and Model: ____________________

____

Planer

Are any trimmings from the planer made into pulp chips? *Yes* ☐ *No* ☐

Which of the chippers listed above receive these trimmings?

First Chipper ☐ *Second Chipper* ☐ *Third Chipper* ☐ *Fourth Chipper* ☐

Comments: ____

____

____

____

Contact Person Filling Out This Form

Name: ____________________

Phone Number: ____________________
(include area code)

Comments: ____

____

____

____

Appendix B

Table B1. Summary of unscreened chip samples from pine sawmill disc chippers (62 samples).

	Chip Fraction				Bark Content	
	Fines	Pins	Accepts	Overs	TBark	ABark[1]
	(percent)					
	0.592	2.888	89.944	6.576	0.963	1.033
	1.452	4.178	74.550	19.820	2.684	1.624
	2.832	2.929	53.592	40.648	1.012	1.012
	1.673	4.546	88.921	4.860	1.094	0.592
	4.555	5.195	74.873	15.377	6.938	5.094
	2.023	1.626	42.898	53.453	1.505	1.709
	3.821	5.049	74.391	16.739	2.541	2.186
	2.121	4.337	80.542	13.000	0.874	0.528
	7.515	3.547	74.586	14.353	3.503	4.168
	2.037	4.113	77.287	16.563	0.000	0.000
	2.215	3.925	81.337	12.523	1.417	0.782
	2.483	2.997	69.497	25.022	4.328	3.281
	3.186	6.074	72.956	17.785	0.024	0.030
	3.269	1.515	76.510	18.706	0.000	0.000
	1.691	3.048	69.639	25.623	0.102	0.140
	2.953	5.377	87.525	4.145	0.135	0.071
	3.184	14.681	77.453	4.683	2.096	2.046
	3.134	16.965	77.608	2.293	3.456	3.182
	2.396	6.995	84.191	6.419	0.210	0.226
	3.824	4.352	84.306	7.518	1.431	1.121
	2.064	4.231	74.093	19.612	2.204	2.037
	2.162	3.527	75.369	18.942	2.627	1.620
	1.707	3.700	59.184	35.409	1.142	0.885
	2.442	4.605	79.908	13.045	0.810	0.578
	1.827	2.542	42.332	53.299	0.407	0.451
	2.016	5.415	88.737	3.832	0.030	0.031
	5.643	7.178	82.567	4.612	0.161	0.088
	1.019	2.146	71.676	25.159	0.544	0.302
	1.110	2.537	79.113	17.240	1.547	1.246
	1.143	3.211	84.953	10.664	2.035	1.432
	2.871	4.033	84.646	8.450	0.100	0.110
	6.229	4.602	79.390	9.779	0.904	0.365
	0.784	3.838	90.694	4.684	0.000	0.000
	2.550	4.792	79.105	13.552	0.181	0.000
	2.627	3.882	81.485	12.007	1.166	0.768
	0.512	1.828	41.448	56.212	0.683	0.845
	3.715	3.816	45.790	46.679	1.567	1.338
	8.779	2.279	66.886	22.055	0.612	0.434
	2.689	4.693	74.791	17.828	0.067	0.069
	4.694	5.243	79.759	10.303	0.307	0.347
	1.413	3.539	85.653	9.394	0.034	0.038
	2.010	5.187	82.757	10.017	0.000	0.000
	2.783	9.670	69.393	18.155	0.378	0.276
	0.980	3.530	89.198	6.292	0.168	0.180
	1.454	2.753	88.241	7.552	0.786	0.720
	1.739	3.829	66.428	28.005	1.886	2.079
	1.753	2.492	47.815	47.939	2.937	2.237
	3.293	5.106	77.703	13.897	0.218	0.148
	3.105	6.474	71.287	19.133	0.254	0.184
	5.006	8.362	71.011	15.621	0.064	0.078
	5.444	2.705	68.167	23.684	4.727	3.929
	1.633	1.957	62.236	33.743	0.363	0.289
	9.685	7.009	65.487	17.819	0.358	0.390
	4.664	2.859	52.719	39.757	0.734	0.959
	4.810	3.385	53.649	38.156	0.324	0.366
	5.423	4.373	77.400	12.804	0.129	0.151
	1.776	3.883	89.898	4.444	0.243	0.185
	1.887	2.804	80.088	15.221	0.744	0.573
	3.963	3.772	61.040	31.225	0.143	0.165
	1.600	1.809	72.988	23.602	0.179	0.232
	1.958	11.774	77.172	9.096	0.141	0.157
	4.624	7.677	65.731	21.968	0.332	0.443
Std.Dev.	1.871	2.819	12.58	13.40	1.352	1.119
Average	2.977	4.635	73.40	18.98	1.073	0.896

[1]TBark represents total amount of bark in the chip sample and ABark represents the amount of bark in the acceptable chip fraction.

Table B2. Summary of unscreened chip samples from chipping heads in pine sawmills.

Head Type	Chip Fraction				Bark Content	
	Fines	Pins	Accepts	Overs	TBark	ABark[1]
(percent)						
4	1.387	2.356	91.992	4.264	1.432	0.962
2	1.200	3.952	75.886	18.886	2.537	1.803
2	1.439	5.669	73.260	19.632	3.648	3.565
2	0.176	0.874	53.784	45.166	1.936	1.290
2	1.489	5.937	76.565	16.008	1.946	1.682
2	3.295	3.092	72.692	20.921	0.771	0.445
1	0.475	3.470	78.610	17.445	0.847	0.454
2	5.119	5.178	83.928	5.776	4.047	2.742
2	6.844	5.376	71.642	16.138	3.252	2.084
2	1.638	2.938	68.888	26.536	2.492	2.289
2	3.357	7.512	85.357	3.775	1.757	0.973
1	1.574	6.727	86.684	5.016	0.070	0.074
4	3.247	12.444	83.382	0.926	0.000	0.000
2	2.055	4.489	64.608	28.847	1.072	1.137
3	1.346	11.190	83.130	4.334	0.839	0.882
2	3.116	4.198	78.473	14.212	0.661	0.481
4	1.544	2.927	66.969	28.561	0.692	0.500
2	1.099	2.950	78.327	17.623	0.072	0.088
2	1.518	5.076	82.083	11.323	0.278	0.297
2	1.693	2.599	51.741	43.967	1.233	1.122
1	2.700	14.268	79.329	3.703	0.393	0.357
2	7.312	3.316	85.419	3.953	0.830	0.469
1	4.277	7.905	82.222	5.596	5.245	4.897
1	6.009	5.435	84.761	3.795	1.028	0.729
4	4.158	4.077	77.688	14.077	0.243	0.126
4	3.780	9.961	84.165	2.094	0.067	0.069
2	2.017	2.824	83.386	11.774	0.140	0.113
2	0.733	1.766	75.008	22.493	0.000	0.000
2	0.797	1.728	84.625	12.850	0.491	0.331
1	2.379	11.871	83.678	2.072	0.086	0.088
4	4.077	6.866	85.516	3.541	0.741	0.550
2	1.365	3.590	72.932	22.113	0.646	0.424
2	3.374	1.979	81.845	12.803	0.326	0.257
2	1.757	2.710	65.217	30.316	0.094	0.138
2	1.130	1.696	42.308	54.866	0.401	0.406
4	3.393	7.704	85.983	2.920	0.000	0.000
2	1.137	2.941	91.146	4.775	0.152	0.160
4	1.396	3.854	87.871	6.879	0.109	0.092
1	2.764	3.974	79.147	14.115	2.405	2.099
4	5.648	7.009	80.988	6.356	0.201	0.217
2	5.015	5.725	86.214	3.046	0.938	0.679
1	1.581	1.745	62.089	34.585	0.643	0.312
2	3.660	3.994	79.370	12.975	0.596	0.478
1	2.512	3.314	83.592	10.582	0.991	0.818
4	1.021	1.501	78.100	19.378	0.222	0.230
1	2.351	13.906	83.469	0.273	0.047	0.047
1	1.859	13.561	84.436	0.143	0.173	0.173
1	1.308	8.138	81.349	9.206	0.067	0.074
1	2.678	8.383	87.136	1.802	2.934	2.886
4	3.720	5.544	78.370	12.367	0.356	0.358
Head Type 1 # Chipping Headrig (13 samples)						
Std. Dev.	1.393	4.341	6.365	9.513	1.531	1.454
Average	2.498	7.900	81.269	8.333	1.148	1.001
Head Type 2 # Slabber/Canter (25 samples)						
Std. Dev.	1.878	1.623	11.740	13.317	1.181	0.937
Average	2.493	3.684	74.588	19.231	1.213	0.938
Head Type 4 # Chipping Edger (11 samples)						
Std. Dev.	1.485	3.363	6.656	8.605	0.432	0.293
Average	3.034	5.840	81.911	9.215	0.369	0.282

[1]TBark represents total amount of bark in the chip sample and ABark represents the amount of bark in the acceptable chip fraction.

Table B3. Summary of screened chip samples from pine sawmills (62 samples).

	Chip Fraction				Bark Content	
	Fines	Pins	Accepts	Overs	TBark	ABark[1]
	(percent)					
	0.600	10.642	83.728	5.029	0.403	0.224
	0.446	8.437	84.841	6.276	0.558	0.497
	0.203	2.447	79.171	18.179	1.519	1.868
	0.360	2.963	77.095	19.582	1.381	0.868
	3.062	5.572	76.635	14.731	1.318	1.187
	0.683	3.248	69.891	26.178	2.088	1.930
	0.374	1.467	89.504	8.655	0.507	0.412
	0.998	3.256	92.006	3.741	0.756	0.613
	1.742	12.698	81.195	4.365	0.352	0.163
	0.605	7.965	85.535	5.895	0.289	0.174
	0.250	1.585	84.064	14.101	0.000	0.000
	0.378	4.101	86.676	8.846	0.065	0.072
	3.968	5.510	80.937	9.585	0.837	0.603
	2.913	3.320	78.243	15.524	0.492	0.360
	0.233	1.272	68.780	29.715	0.147	0.123
	0.408	1.546	81.014	17.032	0.016	0.200
	0.433	1.563	83.271	14.734	0.028	0.000
	0.173	1.860	80.990	16.977	1.261	0.472
	0.122	0.289	51.898	47.691	0.289	0.433
	0.598	3.410	90.179	5.813	0.342	0.223
	0.845	3.143	87.308	8.703	1.281	1.139
	10.027	14.175	75.798	0.000	3.854	3.854
	1.229	13.041	79.204	6.527	0.514	0.353
	0.515	8.117	86.469	4.900	1.539	0.669
	0.270	2.741	81.802	15.187	0.737	0.501
	0.380	3.745	83.326	12.549	0.756	0.504
	1.773	3.087	74.619	20.521	3.986	3.239
	0.975	2.871	88.375	7.779	3.195	2.359
	0.619	2.430	57.173	39.778	1.242	1.117
	0.241	2.484	84.724	12.551	0.425	0.419
	0.372	3.204	87.494	8.930	0.807	0.592
	0.787	4.083	83.612	11.519	0.239	0.239
	0.850	3.812	85.757	9.581	0.197	0.203
	0.200	3.150	85.144	11.506	0.374	0.326
	0.121	3.452	88.760	7.666	0.614	0.392
	0.507	1.697	67.601	30.195	1.481	1.455
	0.560	2.077	74.416	22.075	1.924	1.692
	0.223	1.875	85.054	12.848	0.384	0.218
	0.327	1.676	78.225	19.772	0.766	0.712
	0.228	0.956	70.042	28.774	0.466	0.551
	0.517	3.038	81.601	14.845	0.408	0.205
	0.184	1.830	70.095	27.891	0.379	0.099
	0.209	3.503	79.601	16.687	0.529	0.430
	0.504	6.727	80.979	11.791	1.770	1.579
	0.448	1.349	83.346	14.856	2.505	2.294
	1.672	5.299	87.959	5.070	0.697	0.625
	1.421	4.170	76.104	18.305	0.149	0.070
	1.124	7.354	82.556	8.966	1.404	1.055
	1.845	7.887	83.519	6.750	0.147	0.082
	3.720	6.681	83.260	6.339	0.058	0.063
	0.234	3.673	87.850	8.243	0.136	0.095
	2.742	6.251	80.945	10.062	0.254	0.286
	3.415	6.049	85.529	5.007	4.799	4.722
	2.081	5.034	71.198	21.686	0.033	0.044
	0.586	4.029	85.810	9.575	2.238	1.903
	2.140	2.244	72.558	23.057	0.513	0.409
	0.225	1.441	87.675	10.660	1.065	0.877
	0.155	0.597	84.941	14.306	0.558	0.433
	1.184	3.119	85.752	9.945	0.426	0.458
	0.441	12.338	84.113	3.107	0.270	0.200
	0.324	15.749	79.369	4.657	0.510	0.461
	2.101	8.017	81.449	8.434	1.959	1.507
Std. Dev.	1.499	3.508	7.459	8.99	1.014	0.936
Average	1.079	4.538	80.754	13.62	0.939	0.788

[1]TBark represents total amount of bark in the chip sample and ABark represents the amount of bark in the acceptable chip fraction.

Table B4. Summary of unscreened chip samples from hardwood sawmill disc chippers (26 samples).

	Chip Fraction			
	Fines	Pins	Accepts	Overs
	(percent)			
	0.532	3.364	80.795	15.310
	1.659	1.991	79.997	16.353
	0.36	1.04	87.23	11.37
	2.053	6.038	89.371	2.538
	1.365	4.416	82.157	12.059
	1.773	2.802	85.204	10.221
	0.714	2.121	49.259	47.906
	5.796	7.228	80.057	6.918
	2.357	5.748	61.508	30.389
	11.871	12.822	33.389	41.918
	3.835	5.939	85.535	4.690
	1.715	1.459	83.742	13.084
	6.413	5.853	49.080	38.655
	2.483	2.679	68.294	26.545
	1.193	5.920	90.168	2.719
	0.393	0.939	59.766	38.903
	1.232	2.213	88.578	7.977
	0.741	1.537	82.872	14.851
	1.432	1.366	92.945	4.256
	1.010	2.478	43.028	53.483
	3.001	2.208	82.571	12.221
	3.211	4.119	75.699	16.972
	1.878	1.560	72.823	23.739
	2.992	2.038	85.212	9.758
	3.954	12.804	81.822	1.421
	0.648	1.167	69.486	28.699
Std. Dev.	2.465	3.918	15.961	14.961
Average	2.485	3.219	74.638	18.960

Table B5. Summary of screened chip samples from hardwood sawmill disc chippers.

	Chip Fraction				
	Fines	Pins	Accepts	Overs	TBark
	(percent)				
	1.419	1.842	88.044	8.695	
	0.921	0.949	68.705	29.425	
	0.933	5.933	88.695	4.438	
	0.396	7.246	88.066	4.292	
	0.870	4.471	89.734	4.925	
	0.203	2.787	91.327	5.682	
	0.198	5.982	87.609	6.211	
	0.274	2.686	89.111	7.929	0.29
	1.942	6.457	67.983	23.619	
	1.130	6.747	67.850	24.273	
	1.380	4.012	75.345	19.263	
	1.057	3.791	79.473	15.679	
	0.321	2.214	81.411	16.053	0.09
	0.528	2.557	87.963	8.952	
	0.739	5.300	84.455	9.506	
	0.432	2.019	87.334	10.215	1.66
	1.072	2.226	83.156	13.547	
	0.251	0.560	84.086	15.103	
	0.198	0.327	88.853	10.622	
	0.206	0.402	76.989	22.403	0.22
	0.086	1.066	45.575	53.273	
	0.051	0.573	58.703	40.673	
	0.306	0.420	63.451	35.822	0.43
	0.091	0.431	82.186	17.293	
	2.034	1.233	76.879	19.853	
	2.210	0.690	93.397	3.704	
	1.027	2.614	93.777	2.581	
	0.534	1.509	73.165	24.792	
	0.913	2.757	80.948	15.381	
	0.383	2.610	86.398	10.609	
	0.318	1.183	90.475	8.024	
	0.114	2.814	89.031	8.041	
	0.167	4.898	84.530	10.406	
	0.717	4.483	91.904	2.896	0.73
	0.086	3.159	81.921	14.835	
	0.116	2.796	85.491	11.597	
	2.483	4.332	77.420	15.764	
	0.207	1.885	76.917	20.992	
	0.310	4.106	79.901	15.682	
	0.180	1.876	76.851	21.094	
	0.243	0.974	80.264	18.518	
	0.295	1.714	77.669	20.322	
	0.323	1.524	80.303	17.851	0.09
	0.765	1.254	82.702	15.280	
	0.676	0.948	83.503	14.873	
	0.212	1.011	86.934	11.842	
	0.077	0.445	88.401	11.077	
	0.959	4.339	89.638	5.064	1.73
	0.315	3.681	91.416	4.588	
	0.378	6.088	86.476	7.058	
	0.332	4.129	91.811	3.727	1.55
	0.139	0.606	73.291	25.964	
	1.249	4.739	88.855	5.156	
Number	53	53	53	53	9
Std. Dev.	0.583	1.918	9.32	9.95	0.70
Average	0.619	2.744	82.01	14.63	0.75

[1]TBark represents total amount of bark in the chip sample.

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