FACTORS AFFECTING SAWMILL RESIDUE CHIP QUALITY

by

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(ABSTRACT)

A study was conducted to determine the effects of knife angle, wood temperature, disk speed, anvil condition, and residue type on loblolly pine sawmill residue chip quality. A 152-cm, six-knife, horizontal infeed, top-discharge chipper restored to factory specifications was used as the test machine. Chips were recovered after being blown 4m vertically through a cyclone settler onto a screen pack with the top screen blinded. Oversize chips were not re-chipped. Material types included cants as controls, slabs, edgings, and trim blocks. Chipper rim speeds included the manufacturer's recommended 3,385 meters per minute along with 2,370 meters per minute and 1,693 meters per minute achieved by the drift-down method. Knife angles included 30, 31, 32, and 33 degree straight grinds. Wood temperatures ranged from ambient temperatures of over 21 degrees C. through chilled (approximately +2 degrees C.) and frozen (-4 degrees C.). The chip distributions from chipping slabs and edgings were not significantly different from those of the cants. Less than 50 percent of the weight of

the trim blocks was returned as acceptable chips in most trials. Reducing disk speed resulted in a major reduction in pin chips and fines. Knife angles had less effect on chip size distributions than any of the other variables tested. The percentage of pin chips and fines was greater for chilled and frozen wood than for wood at ambient summer temperature.

ACKNOWLEDGMENTS

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CHAPTER 1. INTRODUCTION

In today's pulp and paper industry, product quality is becoming a greater concern than quantity. In the past, mill managers were mainly concerned with operating their mills at or near full capacity. Chippers were purchased on the basis of cost, throughput capacity, power requirements, and ease of operation instead of the quality of chips produced (Hatton 1979). The competitiveness of today's markets demand that mills produce a higher quality product than they have in the past. In order to produce high quality products, they must start with high quality materials.

Before the 1970's, chips were produced mainly in pulp mill wood rooms from debarked, sound boles of preferred species. Thus, there were no large variations in chip quality since the mills had control of the chip supply (Hatton 1987). Today, most mills rely on two sources of wood chips: those they produce in their own mill wood rooms or satellite woodyards, and those purchased from outside suppliers, mainly sawmill residue chips. In Canada, it is estimated that pulp mills obtain 50% of their fiber from sawmill residues (Hatton 1988). The invention of the rotating-ring mechanical debarker in approximately 1950 increased the supply of bark-free chippable wood available for pulp fiber from sawmill slabs and veneer mill clippings (Koch 1972). The estimated overall average of chippable

residue for southern pine is 1.6 tons of green chips per mbf (Doyle scale) of logs sawn. Small logs yield substantially more chips per bd. ft. than large logs. For example, 26 inch (66.04 cm) butt logs, eight feet (2.44 m) in length yield approximately .76 tons of green chips per mbf. Eight inch (20.32 cm) butt logs, eight feet (2.44 m) in length yield approximately 1.92 tons of green chips per mbf, two and one-half times that of the 26 inch logs (Koch 1972). These sawmill chips utilize what would otherwise be considered waste: thus they do not add to the forest drain (Britt 1970).

This increased use of sawmill residue chips creates a problem in the quality of chips that reach the digesters. Whole logs give uniform chips: chippers chipping small slabs and trim blocks generate non-uniform chips (Christie 1986). These variations in particle size distributions have an impact on product yield and quality and often lead to excessive energy and chemical consumption. Pins and fines seem to have the greatest impact on cooking processes. Most mills have elaborate screening systems to screen out pins and fines which are then sent to the boilers as fuel, resulting in a substantial loss of fiber. A two percent increase in the useable fiber reaching the digesters can have a significant economic impact on the mill. For example, if a mill runs three shifts per day, uses 70 cords of wood per hour, and the prices for pulp mill chips and

hogged fuel are $60/cord and 20$/cord respectively, a two percent increase in the amount of fiber going to the digester instead of the boiler would save the mill approximately $336,000/year at the chipper. These savings would multiply on down the system by decreasing cooking time, reducing sewage and landfill volumes, and increasing pulp quality (Robinson 1987).

Because sawmill residue chips are such an important source of fiber, it is essential that ways are found to increase the quality of this fiber source. As stated above, small increases in useable fiber yields from chips can have significant economic impacts for the mill.

OBJECTIVES

The objectives of this study were:

1) To compare the effects of chipper disk speed, knife angle, anvil wear, and wood temperature on sawmill residue chip quality.

2) To determine if the principles governing roundwood chipping apply to sawmill residue chipping.

3) To present the information in a form useable by chip suppliers to aid them in making decisions concerning purchasing new equipment, modifying

existing chippers, or correcting chronic chip quality problems.

CHAPTER 2. LITERATURE REVIEW

THE EFFECTS OF CHIP QUALITY ON PULPING CHARACTERISTICS

The term "chip quality" encompasses many different properties: mean particle size and particle size distribution, bark content, moisture content, bulk density, chip origin, and chip damage to name a few. Different pulping processes have different requirements regarding chip quality and specifications. Mechanical and sulphite pulping processes require much higher quality standards than kraft processes. This does not imply that wood quality is not important to the kraft process. The kraft process is versatile and thus can be adapted to a variety of wood conditions, but the properties of the raw material influence the quality of the final product (Bergman 1985). No matter what the pulping process, the chemicals must penetrate the wood completely and uniformly for efficient production of high quality pulp (Hatton 1979).

Chip thickness appears to be the most important parameter in the kraft pulping process. Sulphite pulping, on the other hand, requires stringent control of chip length, thickness, and damage. An undisturbed constant flow of chips into the refiner is critical to the refiner-mechanical pulping process. Thus, uniform particle size distributions are required along with high moisture contents

(complete saturation is the ideal situation). When Kamyr continuous digesters are used, the percentages of pins and fines must be minimized in order to facilitate the flow of cooking liquors through the circulation system (Koch 1985).

Hatton (1979), recommended the following chip requirements regardless of the pulping process used:

- consistency in chip density
- low bark content
- very low hard impurity content (sand).

The presence of sand is particularly undesirable in the production of refiner-mechanical pulp and high yield pulps with in-line refining because of the added wear on refiner plates.

As mentioned above, chip damage is especially critical in the sulphite pulping process, contributing substantially to pulp strength losses with associated reduction in pulp yield. The damage is caused by the chipper knives themselves. In disk chippers, the knives have a finite thickness. Thus, compressive stresses develop on the end of the chip ahead of the knife before the chip is sheared from the log. As a result, each chip has one clean-cut end and one with compression damage, called brooming. The extent of this damage depends on chipper variables and the condition of the wood (Christie 1986).

A summary of the effects of chip specifications in pulp processing is listed in Table 2.1.

Table 2.1 - Effect of chip specifications in pulp processing (Hatton 1987).

Chip Parameter	Pulping Process			
	Kraft	Sulphite	NSSC	Refiner-Mechanical
Length preferred range, mm.	Not too critical 15 -25	Critical 25 -35	Not Known	Not known
Width	Not critical	Not critical	Not critical	Not known
Thickness preferred range, mm	Very critical 1.5 - 4 (solid wood)	Not critical*	Not known	Not known
Chip density	Consistency critical		Consistency critical	
Bark content preferred range, %	Critical for production economy	Very critical < 1	Critical for production economy	Critical
Hard impurities (sand, metal)	Critical for high yield	Critical for dissolving pulp	Very critical for plate life	
Chip damage	Not critical	Very critical	Not critical	Not known
Moisture content	Not critical	Not critical	Not critical	Very critical

* With increasing chip length in sulphite pulping chip thickness assumes increasing importance for ease of liquor penetration.

The goal of any wood room manager is to produce chips within a narrow particle size distribution, even when the quality of the wood furnish changes. This is particularly difficult when chipping small pieces, such as those chipped in sawmill residue chippers (Bergman 1985).

THE EFFECTS OF CHIPPER DESIGN CHARACTERISTICS ON CHIP QUALITY

Residue chippers in sawmills are typically disk chippers with three to six knives. Smaller disks have higher rotational speeds than larger disks in order to achieve similar knife speeds. A mill equipped with a head saw and an edger (as opposed to a chipping headrig and edger) that produces 10,000 bd. ft. of lumber per hour might chip all its residues in one chipper. The chipper would typically have a 58 inch disk with six knives, turn at 720 RPM, and be powered by a 150 hp. squirrel-cage induction motor. The output would be approximately 15 tons of green chips per hour (Koch 1972).

Sawmill residue chippers deal with a different classification of material than the conventional roundwood chipper, thus the mechanics of chipping may differ. A classification of sawmill residues is listed below.

Slab: Semi-circular arch from the exterior of the

log with acceptable length parallel to the grain (similar to a log) except it is thinner. Probably lies flat in the chipper spout with flat side either up or down. Chipper tends to run out of wood as the knife passes because of thinness.

Edging: Lack thickness in length and width, with acceptable length parallel to the grain. Low cross section to length ratio: knife will run out of wood. Anvil clearance likely to be critical to minimize production of splinters and pins.

Trim Block: Good cross-sectional area. High cross-section to length ratio. Bounce and orientation difficult to control.

One of the basic problems encountered in the use of residue chippers is the feeding of the slabs and edgings into the machine. Large diameter wood tends to produce chips of much higher quality than smaller wood. The main reason is that large logs are more easily controlled and stabilized in the infeed spout than small pieces. Small pieces of slabs and edgings do not always reach the chipper oriented properly. Thus, they tend to interfere with each

other during the feeding process. Pieces of wood that tend to bounce around in the infeed spout will produce more pins and fines than those that are somewhat stable.

Robinson (1987) concluded that fines are produced because log movement results in irregular feeding and non-uniform breaking off of chips. During this process, the angle of feed may, at times, be greater than the spout angle. When the log axis feed is steeper than the spout angle, overs may be produced.

Disk Speed

The speed at which a disk rotates can have a pronounced effect on the particle size distribution of the chips it produces. According to Hartler (1985), when the speed is set too low, the wood only cracks and does not fully split up into distinct pieces. This results in cakes of wood containing cracks, often called cards. As the speed is increased, production is increased, but the percentage of undersize fractions produced also increases. This relationship is illustrated in Figure 2.1. As a result, he recommends a cutting speed of 20 - 25 m./s.

The work done by Robinson (1989) supports this. He conducted an experiment in which he compared the percentage of undersized fractions (pins and fines) produced by a bottom discharge chipper without card breakers at two

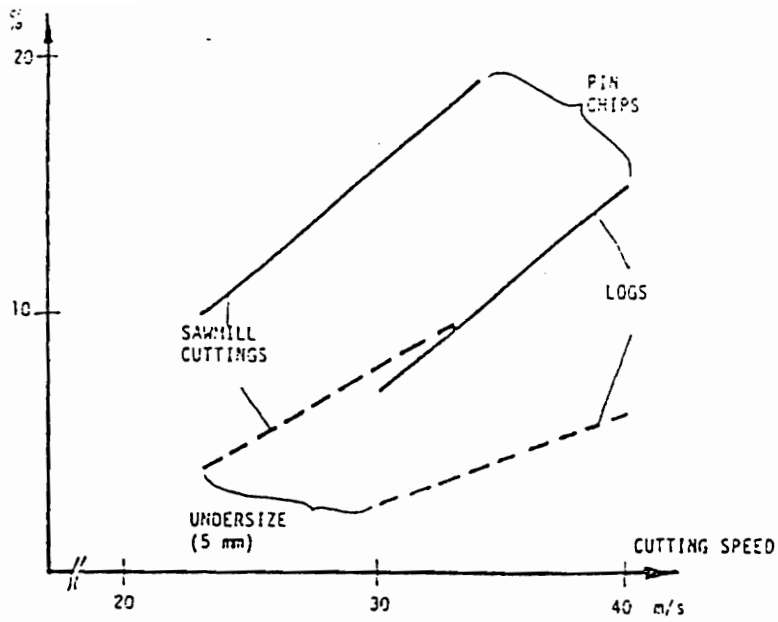

Figure 2.1 - Relationship between the undersize fractions for spruce logs and sawmill cuttings and the cutting speed (Hartler 1985).

different rim speeds: 53.6 m./s. and 44.6 m./s. The disk turning at 53.6 m./s. produced 19% pins and fines (as measured by a Williams chip classifier) while the disk turning at 44.6 m./s. produced only 7% pins and fines: a significant difference. The results obtained when comparing speeds in a top discharge chipper were similar: 55.5 m./s. cutting speed produced 30% pins and fines and 46.2 m./s. cutting speed produced 20% pins and fines.

As post processing (impacts, pneumatic conveyance, top discharge) increases, the production of pins and fines increases. The additional post processing occurring in top discharge chippers can be compensated for by using slower disk speeds. However, slowing the disk speed will reduce the number of cuts per minute which in turn reduces chipper production, affects motor power requirements, and will restrict blowing capabilities (Robinson 1989).

Knife Angle

Just as disk speeds play an important role in chip quality, so do knife angles. Many people have explored this area, trying to come up with the ideal angles to use on chipper knives. In 1961, E. L. Crowley and N. P. Wardwell of Carthage Machine Co. wrote an informative article entitled "The Norman Chipper-Theory and Practice". In this article, they explained the theory of chipping in general,

and how it especially applies to the Norman type chipper designed by the Norwegian engineer, Sigurd Norman, for which a patent was issued to him in December, 1939.

During the chipping process, the logs are pulled against the disk by the knives. As the knife slices through the log, the cut face follows the adjacent knife surface as far as possible. Ideally, as the log is pulled in, it will be ready for another cut just at the time it reaches the next chip slot.

The angle formed between a vertical line and the adjacent knife surface is called the pull-in angle by the people at Carthage Machine Co. The term for this angle used by the rest of the industry is rake or clearance angle (Figure 2.2). This angle must be right in order for the logs to feed properly. Following is a discussion of the problems encountered when this angle is not set properly.

When the angle is too large, the knives create too much pull-in. The consequences of this angle are as follows:

1) The wood is forced against the face of the chipper which creates extra wear on the disk wear plates. Longer chips are cut when the log encounters these worn spots.
2) The extra forces created by the stronger pull-in put a severe strain on the chips. This produces bruised and compressed fibers, rough chips, and sawdust.

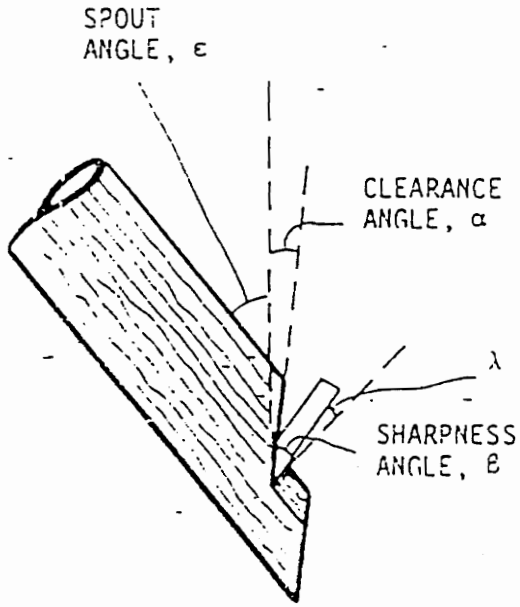

Figure 2.2 - Knife position shown in relation to the log (Hartler 1985).

3) The strain is transmitted to the log which tips up, causing the knives to cut progressively shorter chips as they proceed into the log.
4) If a small log is pulled in too soon, it may bounce away before the next knife makes contact.

When the angle is too small, the knives do not create enough pull-in. The consequences of this angle are as follows:

1) The log is not pulled in far enough, thus the percentage of shorter chips produced increases.
2) The knife resists pull-in because the trailing edge of the knife is too high to allow the log to slide toward the disk until the knife is completely disengaged. The knife tip may wear until the angle approaches zero. At this point, the logs cease to feed.
3) The knife tip might wear enough to produce a negative pulling effect. Short pieces, especially those encountered in sawmill residue chippers may fly back up the chute, creating an extremely dangerous situation. This seems to happen more in cold weather or with very hard wood.

After viewing these potential problems, it is obvious that the pull-in angle must be correct. Crowley and

Wardwell (1961) recommended making the angle as large as possible to avoid the hazards of it being too small. Thus, the knives must be close enough together to avoid the angle being too large. Setting the knives to produce a shorter chip reduces the angle. In this case, it is important to have the knives closer together. On large chippers, the knives on the outside of the disk are always far apart. To counteract this, the design of the Norman chipper is such that the number of knives are increased and they are mounted as near the hub as possible.

In 1963, J. G. Buchanan and T. S. Duchnicki did some work with an experimental laboratory scale chipper. The work concentrated on the effects of knife angle on cutting forces required and the amount of damage occurring during chipping. The knives were one inch wide and at angles of 20, 30, 40, and 50 degrees. All the knives were kept in freshly sharpened condition throughout the experiment. Some of their conclusions are listed below.

1) Peak cutting forces increase with increasing knife angles.
2) Chip thickness increases with increasing knife angle and moisture content of the wood.
3) As the knife angle increases, compression parallel to the grain increases in the area adjacent to the knife.

4) Work increases with increasing knife angle.

5) There was little increase in chip damage with increasing knife angle until the 50 degree knife was used, then the damage increased sharply.

Since these results were obtained with a laboratory chipper, a direct comparison cannot be made to a commercial chipper. However, the basic principles developed may provide insight to future experiments on commercial chipping operations.

Even though knife angle appears to be extremely important, Hartler (1985) also stresses the importance of keeping the knives sharp. A decrease in sharpness angle can be favorable, but the ability of the knives to remain sharp during cutting decreases with decreasing angle. Most mills use angles between 30 and 35 degrees: the larger angles being more durable.

Backgrinding the knives (1/8 inch by 3-7 degrees max.) may improve chip quality and knife durability. It is recommended that the chipper manufacturer be consulted first if the knives are not normally back-ground (Robinson 1987).

Anvil Wear

The anvil (or bedknife, as it is sometimes called), is another part of the chipper that leaves little room for

variation in its settings. In most chippers, Hartler (1985) recommends that the anvil clearance be set as small as possible, usually between .5 mm. and 1 mm. Settings larger than this will cause the chipper to produce more pins and fines, or it may allow slivers and strings to pass between the spout and disk instead of through the knives and chip slot. The production of pins and fines in relation to the anvil clearance is illustrated in Figure 2.3.

The optimum spout angle is between 34 and 45 degrees, measured to the face of the disk. This results in a round log appearing elliptical at the disk face. It is critical that all logs feed at the same angle to the disk (Figure 2.4).

Robinson (1987) looked at the importance of bedknife and spout wear. Usually, the log projects in front of the bedknife a distance of .5 mm. to 1.0 mm. As the spout and bedknife wear, the log tips up because the forces from the knife point and bedknife exceed the gravitational force holding the log on the spout. When this happens, a longer chip is cut (Figures 2.5 and 2.6). Also, the log may tip back and forth creating variable length chips.

If a worn bedknife is replaced, and the equally worn spout wearplates are not, a number of events might occur:

1) The logs will skip up and hit the disk where they may be partially chipped unsupported by the

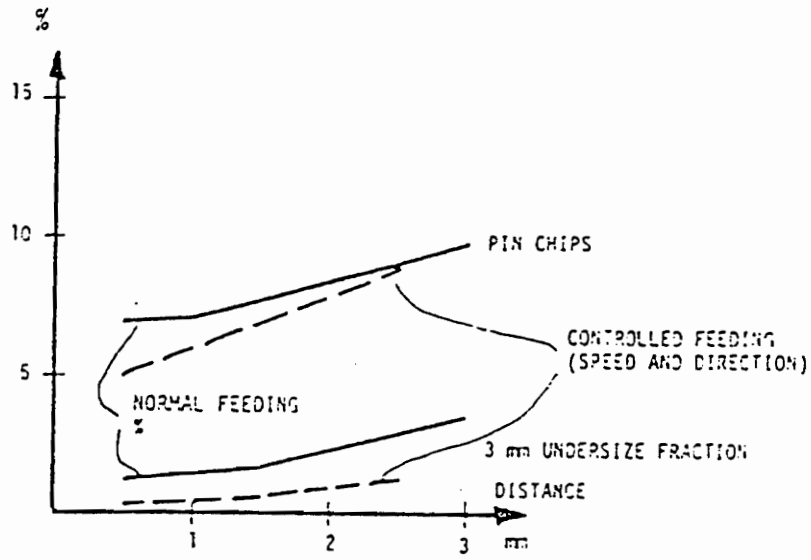

Figure 2.3 - Relationships between undersize fractions and distance between knife and bedknife edges using normal and controlled (correct speed as well as direction) feeding (Hartler 1985).

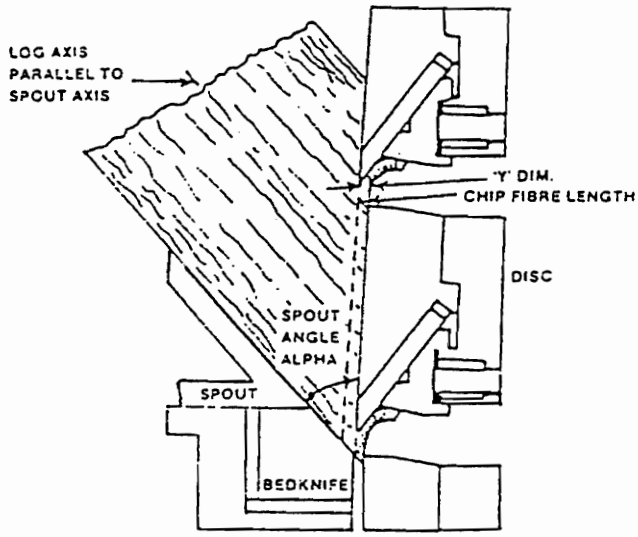

Figure 2.4 - Constant spout feed angle (Robinson 1987).

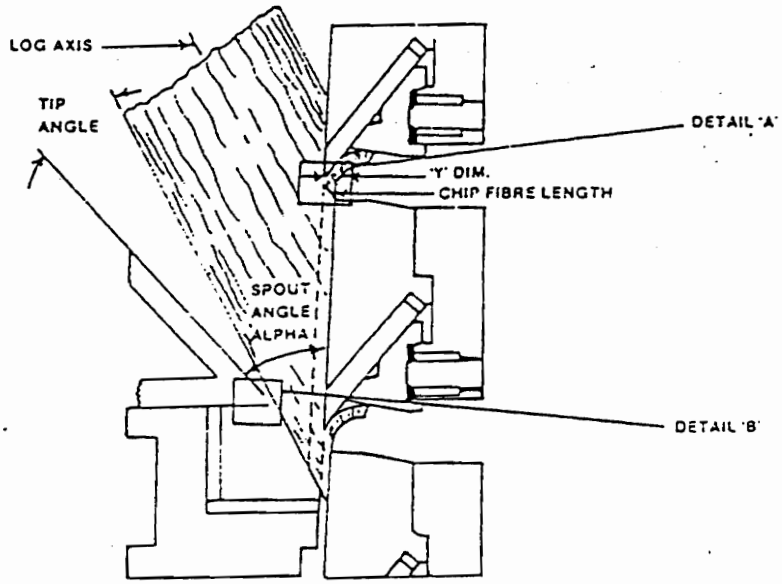

Figure 2.5 - Worn bedknife and spout (log tips up) (Robinson 1987).

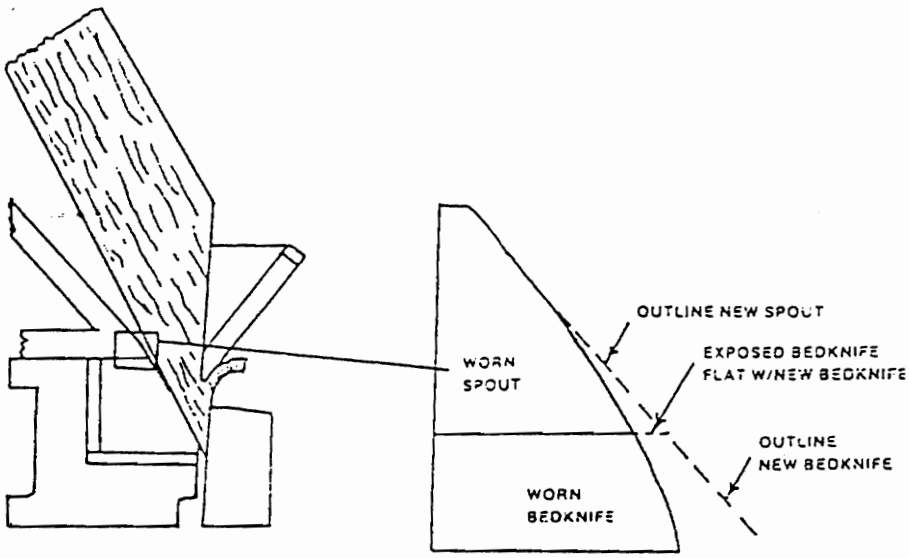

Figure 2.6 - Effects of worn bedknife and spout (Robinson 1987).

bedknife. This will increase the number of short chips and fines produced.

2) The logs will feed poorly, thus reducing knife life.
3) The new bedknife will wear faster. To detect this situation, look into the chipper spout. If the bedknife flat is visible at the bedknife to spout fit, the spout (wearplates) needs repair or replacement (Robinson 1987).

Number of Blowing Vanes

In top discharge chippers (typical of sawmill residue chippers) there are a number of vanes fixed to the back of the disk which strike the chips and cards and sling them through a spout and into piping for further conveyance. This additional force and impact placed on the chips breaks them into smaller fractions. In a study reported by Robinson (1989), a chipper containing only one-third of its original set of blowing vanes produced more than two-thirds of the total breakage produced with a full set. In his 1987 paper entitled "Effect of Chipper Design and Operation on Chip Quality", he recommends running a chipper with the fewest number of vanes necessary for balance, additional post processing, and material conveyance. More post processing than the minimum required produces more pins and fines. He also states that some chips are crushed between

the vanes and the chipper casing. If the speed is decreased or if vanes are removed to decrease this damage, the ability of the chipper to blow the chips may be hindered, thus causing plugs in the blowline. In most cases, the conveyance of the chips is considered more important than chip quality, so chip quality usually suffers. In Robinson's opinion, the best chipper discharge method is gravity. In those systems, slower disk speeds are feasible and the amount of post processing can be adjusted.

Seasonal Effects

In cold weather, chips break up more finely. In a study reported by Robinson (1989), the percentage of fines produced as a result of temperature ranged in a curvilinear relationship from 27% at -22 degrees C to 15% at 10 degrees C. In order to compensate for this, the pull-in angle can be increased within limits without changing the chip length, but that increases the chances of the problems associated with pull-in angles that are too large. In warm weather, the chip length and pull-in angle can be returned to normal (Crowely 1961).

Most of the work on chipper design characteristics and their effects on chip quality has been done on pulp mill woodroom chippers chipping roundwood. Little work has

concentrated on sawmill residue chippers. Some basic principles of chipping roundwood will apply to sawmill residues, but many of the accepted truths may not. Because of the problems (orientation and stabilization) encountered when feeding sawmill residues into a chipper, a knife angle that would normally be too large for chipping roundwood may prove to be beneficial by providing a more stabilized feed.

CHAPTER 3. METHODS AND PROCEDURES

A series of ten trials were conducted at Chesapeake Corporation's West Point, Virginia hardwood sawmill in mid-July 1990. The effects of wood temperature, knife angle, chipper disk speed, anvil condition, and material type on the size distribution of sawmill residue chips were studied. Particular attention was given to reducing the percentage of chips over 8mm thick and the percentage of pin chips and fines.

EXPERIMENTAL SETUP

Equipment

The chipper used was a Fulghum Industries 60 in. (152 cm) diameter, six-knife, vertical disk chipper turning at 707 rpm (3385 m/min.) and powered by a 200+ Hp (150+ kW) electric motor. It had a horizontal vibrating conveyor for the infeed and a top discharge with three blowing vanes. Before the trials, the chipper was restored to factory-fresh conditions by the manufacturer.

Under normal operating conditions, the chips were blown into a cyclone settler and then dropped onto a gyrating two screen pack. The top screen retained the oversize chips and diverted them back to the infeed conveyor for rechipping.

The pins and fines passed through the bottom screen and were diverted to the sawdust conveyor and used for fuel. Pulpable chips were retained on the bottom screen and conveyed to a rotary valve that directed the chips to a blower which loaded a chip van.

For the purpose of this study, the top screen was blinded with plywood so that the entire flow of chips was diverted down the chute normally used for carrying oversize chips back into the chipper infeed. The chute was extended over the chipper infeed conveyor and onto the concrete pad adjacent to the chipper so that the chip flow could be sampled.

Although the West Point mill is a hardwood sawmill, its location, ease of access to the chipper, and the availability of Loblolly pine in the immediate area made it suitable for this study. The equipment used in this study - chipper, conveyors, and screens - are commonly used in both hardwood and softwood mills. The debarker at the West Point mill, a rosser head, is the only piece of equipment not consistent with a pine sawmill setup.

Test Material

Four material types were included: cants (15cm x 15cm timbers), slabs, edgings, and trim blocks. The slabs, edgings, and trim blocks were produced from a 20 metric ton

load of freshly cut Loblolly pine (*Pinus taeda* L.) delivered to the mill the week preceding the trials. The timbers were purchased locally. The slabs consisted of pieces of random widths and lengths collected from the system during the initial breakdown of the logs. The edgings consisted of one and two inch (2.54 and 5.08 cm) square pieces approximately eight feet (2.4 m) in length. The trim blocks consisted of two, six, and twelve inch (5.08, 15.2, and 30.5 cm) long by one and two inch (2.54 and 5.08 cm) thick pieces of various widths. The mixture of trim blocks was by weight 40% 12 inch (30.5 cm) pieces, 40% 6 inch (15.2 cm) pieces, and 20% 2 inch (5.08 cm) pieces. The cants, 6 in. x 6 in. (15.2 cm x 15.2 cm) timbers (hence forth called 6x6 cants), weighing approximately 200 lbs (90 kg) each, were purchased locally since not enough material could be produced from the original load of logs. The cants served as a standard of comparison appproximating roundwood chipping for the other materials types. A mix of slabs, edgings, and trim blocks was also used to approximate the normal material flow to the chipper. The mix consisted of (by weight) 40% slabs, 35% edgings, and 25% trim blocks. The mixture essentially served as a fifth material type.

TRIALS

Five types of trials were used: two control trials,

three knife angle trials, two temperature trials, two disk speed trials, and one worn anvil trial. The ten trials conducted included the following:

- beginning control
- 30 degree knife angle
- 32 degree knife angle
- 33 degree knife angle
- chilled material (+2 deg. C)
- frozen material (-4 deg. C)
- 60 percent disk speed (424 rpm)
- 80 percent disk speed (566 rpm)
- worn anvil
- ending control.

Controls

The beginning and ending control trials were used to monitor any significant changes that may have occurred in the physical characteristics of the chipper during the course of the trials. The controls were run with the wood at ambient temperature {95 deg. F (35 deg. C)} and the chipper at factory fresh condition with all other manufacturer's recommendations in effect (31 deg. knife angle, 707 rpm disk speed, new anvil). One of the control trials served as the 100% disk speed for the speed trials, the ambient temperature for the temperature trials, and the

new anvil for the anvil condition trial.

Knife Angle

For the knife angle trials, four sets of new knives were used, each sharpened to one of the four angles tested (30 deg., 31 deg., 32 deg., 33 deg.,). The manufacturer's recommended angle of 31 deg. was used as the control. In each of the trials, the chipper was run with the new anvil, at 100% disk speed (707 rpm), and the wood at ambient temperature.

Temperature

The wood used for the temperature trials was placed in a refrigerated van set at 20 deg. F (-4 deg. C) for several days before the trials were run. The frozen wood was brought to a temperature of -4 deg. C and the chilled wood was brought to a temperature of +2 deg. C. The wood was removed from the van only as needed to insure that the temperatures were maintained at the desired levels. A temperature probe was used to determine the temperature of each bundle of material before it was chipped to confirm that it was at the desired temperature. The temperature trials were run with the new anvil, at full disk speed of 707 rpm, and with a knife angle of 31 deg.

Disk Speed

The two speeds for the speed trials were obtained using the drift down method described by Robinson, 1989. The material was moved to the chipper infeed spout and the vibrating conveyor was stopped. The chipper motor was shut off and the disk was allowed to slow down. When the disk speed was 35.5 rpm above the desired test speed, the conveyor was started, allowing the wood to enter the chipper. The disk speed was monitored using a Monarch digital optical tachometer, model TACH-IVR. The theory was that the chipper would reach the desired test speed midway through the chipping process and finish chipping each batch at 35.5 rpm below the test speed; thus the desired test speed would be the average speed for each batch. The speed trials were performed with the new anvil, 31 deg. knife angle, and the wood at ambient temperature.

Anvil Condition

For the worn anvil trial, the new anvil was replaced with an extensively worn anvil. The wood was at ambient temperature, the knife angle was 31 deg., and the disk was run at 707 rpm.

PROCEDURES

Each trial consisted of three replications of test batches for each of the five material types for a total of 15 replications per trial. The disk speed and first control replications were randomized together for a total of nine randomized replications. The temperature, knife angle, and worn anvil trials were run as a series because of the time and expense associated with making changes to the chipper. The order of material types sent to the chipper was 6x6 cant, slabs, edgings, mixed furnish, and trim blocks. The order of material types was not randomized for each trial (Table 3.1).

DATA COLLECTION

Sampling Method

Chip Size

Bundles weighing 200 pounds (90 kg) of each material type were chipped for each of the three replications. As mentioned previously, the top screen of the gyrator was blinded and the chip stream was temporarily by-passed to the extended overthick chute so that the entire chip stream could be sampled. Five bucket samples, each weighing

Table 3.1 - Replication order of trials.

Trial	Replication #
Beginning Control	1
80 % Disk Speed	1
60 % Disk Speed	1
60 % Disk Speed	2
Beginning Control	2
80 % Disk Speed	2
80 % Disk Speed	3
60 % Disk Speed	3
Beginning Control	3
Chilled	1
Chilled	2
Chilled	3
30 deg. Knife Angle	1
30 deg. Knife Angle	2
30 deg. Knife Angle	3
32 deg. Knife Angle	1
32 deg. Knife Angle	2
32 deg. Knife Angle	3
33 deg. Knife Angle	1
33 deg. Knife Angle	2
33 deg. Knife Angle	3
Worn Anvil	1
Worn Anvil	2
Worn Anvil	3
Frozen	1
Frozen	2
Frozen	3
Ending Control	1
Ending Control	2
Ending Control	3

approximately 20 pounds (9.08 kg) were taken from the chip stream by alternating bucket sequence (the first bucket filled was rejected, the second kept as a sample, the third rejected, etc.), until a total of five samples were obtained. Immediately after each sample was collected, the bucket was emptied into a labeled plastic bag and the bag was sealed to prevent any moisture loss from the chips.In total, approximately one half the weight of the input material was retained as samples. The samples were obtained in this alternating fashion so that the entire chip stream was sampled for each bundle chipped. The first bucket collected was not used to avoid any initial stratification of the chip stream on the gyratory screen and to avoid any end chips that would be present. The last bucket collected was not used to avoid any stratification of the latter part of the chip stream. After the last sample was collected, the screens were allowed to purge of any remaining chips before the next bundle was chipped to prevent contamination between samples.

Moisture Content

Samples for moisture content analysis were taken in a manner similar to that described above at the same time the samples for size classification were being taken. Three one pound (450 gram) samples were obtained from the odd numbered

buckets starting with the third bucket collected from the chip stream. The samples were immediately sealed in labeled plastic bags. Moisture content samples were taken for each material type within each replication of each trial. The moisture content data was used to verify that any variability in the chip size distributions was not affected by variations in wood moisture content between batches of materials.

All of the samples (size classification and moisture content) were taken to the Industrial Forestry Operations Laboratory for measurement.

Sample Measurements

Moisture Content

The first analytical operation performed after returning to Virginia Tech was the initial weighing of the moisture content samples. Each sample was emptied into a labeled paper bag and the bag and chips were immediately weighed. An average weight of the empty bags was determined and was tared from the total (bag plus chips) to determine the initial weights of the chip samples. After all the samples were weighed, they were placed in a low temperature dryer to remove all the moisture from the chips. The moisture passed through the paper bags, allowing the chips to dry

completely. The samples were placed on expanded metal shelves within the dryer. High power heater bulbs underneath the shelves were used to raise the temperature within the dryer to approximately 150 deg. F (65 deg. C). The temperature within the dryer was maintained at or below 150 deg. F (65 deg. C) to prevent volatile extractives from being driven off from the wood. The humid air was exhausted by a small fan located at the top of the dryer.

After approximately one week of drying, the weights of a few of the samples were checked daily to determine when the sample weights had stabilized. When the sample weights had stabilized, all the samples were removed from the dryer and weighed. The average bag weight was tared from the totals (bag plus chips) to determine the dry, final chip weight. The data was entered into a spreadsheet to determine the moisture content (wet weight basis) of each sample. All measurements were taken to the nearest one-tenth of a gram.

Chip Size

The chips were evaluated using a Williams Classifier. A bar screen was used to separate out all material over 8mm in thickness. Seven round-hole screens of decreasing diameter were used to classify the material passing through the 8mm bar screen (Figure 3.1). The classification was done using a two stage process. The first pass removed the overthick

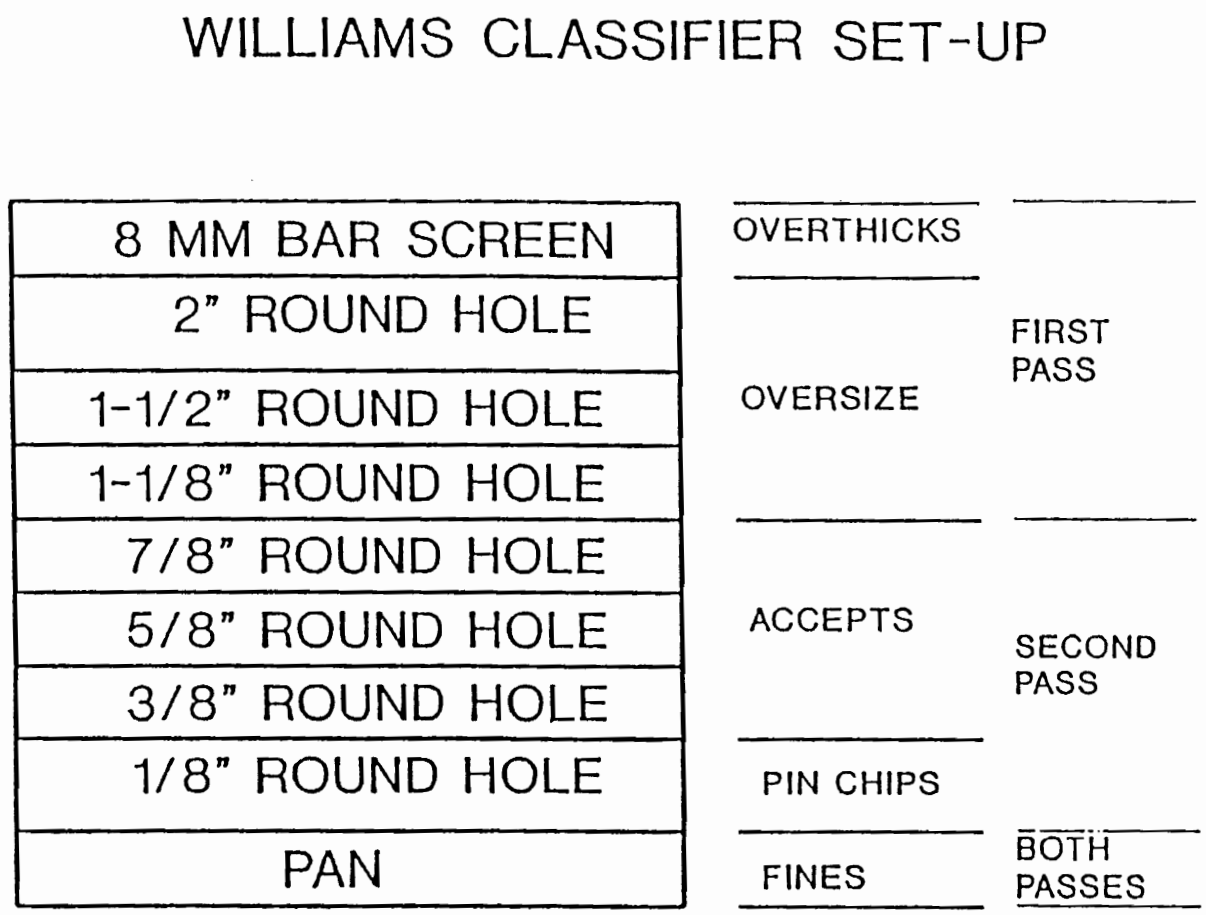

Figure 3.1 - Williams Classifier two-pass setup.

and oversized material. Approximately one-half of the contents of each sample bag was first sorted through a five screen stack consisting of an 8mm bar screen and 2-, 1-1/2-, 1-1/8-, and 1/8-in. (50.8-, 38.1-, 28.6-, and 3.18-mm) round-hole screens. The 1/8-in. (3.18-mm) round-hole screen retained all of the material passing through the 1-1/8-in. (28.6-mm) screen minus some of the finer material that passed through it and was retained in the bottom pan. The classifier was operated for three minutes, after which the screens were removed and the retained chips (with the exception of the material collected in the bottom pan) were weighed. The chips were weighed to an accuracy of one-tenth of a gram on a Sartorius PT1200-OUR. The classifier was then reassembled with the second stack of screens [7/8-, 5/8-, 3/8-, 1/8-in. (22.2-, 15.8-, 9.53-, and 3.18-mm) diameter holes]. The classifier was again operated for three minutes, after which the screens were removed and the retained chips (including those in the bottom pan) were weighed. As each trial was completed, the data was entered into a spreadsheet to determine the percentage (by weight) of each size class of chips produced.

DATA ANALYSIS

The Number Cruncher Statistical System was used to develop descriptive statistics: mean, median, and confidence

intervals. Tests of normality were used to determine if the data were skewed, or if it followed a normal distribution. This preliminary analysis indicated that the data were mostly normally distributed and that the means best conveyed the sense of the data. Thus, parametric statistics were used for the analysis. The two-sample t-test was used to compare the results of the experimental trials with the control trials and between material types (the 6x6 cants and the slabs, edgings, trim blocks, and mixed material type). The weights of each chip size fraction were transformed into percent weight so that the comparisons could be made on an equal basis. The null hypothesis is "the means are equal". The alternate hypothesis is "the means are not equal". All t-tests were run with a two- tailed rejection region.

CHAPTER 4. RESULTS AND DISCUSSION

CONTROL TRIALS

The control trials were conducted to monitor the beginning and ending condition of the chipper and to serve as a standard of comparison for the tests. One of the control trials served as the 100% disk speed for the speed trials, the ambient temperature for the temperature trials, the new anvil for the anvil condition trial, and the manufacturer's recommended knife angle of 31 degrees. Two-tailed, two-sample t-tests were run to test for significance between the two controls. The first control was performed before the rest of the tests using all of the manufacturer's recommended specifications. At the end of all the tests, the chipper was once again set to factory specifications and another control was run to determine if significant changes in the chipper condition had occurred over the course of the trials.

The results of the tests between the two sets of data are presented in Table 4.1. Twenty-seven of the 45 tests failed to reject the null hypothesis. Of the 18 tests that rejected the null hypothesis, 11 were within the accepts category (those chips retained on the 7/8-, 5/8-, and 3/8-in. screens). Since there was no major difference among chip portions (overthick, oversize, accepts, pin chips,

Table 4.1 - P-level for two-sample comparison of the first and second control.

Trial	Material	8 mm	2"	1-1/2"	1-1/8"	7/8"	5/8"	3/8"	1/8"	PAN
SECOND CONTROL	CANTS	**				**		**		
	SLABS		***		***	****		**		
	EDGINGS					**	****		***	****
	MIXED			**			**	**		
	BLOCKS	*				*	****	*		

LEGEND

SYMBOL	P-VALUE		S. L.
*	(10%	0.100)	90%
**	(5%	0.050)	95%
***	(1%	0.010)	99%
****	(.1%	0.001)	99.9%

fines), it was inferred that the condition of the chipper remained constant throughout the trials. Thus, the first control was selected as the standard for comparison for the other trials. The data from the two controls could not be pooled because their variances were unequal.

EFFECT OF KNIFE ANGLE ON CHIP SIZE DISTRIBUTION

Four new sets of knives were used for the knife angle trials, each sharpened to one of the four angles tested (30 deg., 31 deg., 32 deg., 33 deg.). The manufacturer's recommended angle of 31 deg. was used as the control.

The chip size distribution based on chip length and width for the 31 degree knife angle used as the control is illustrated in Figure 4.1. Since overthick chips are measured on the basis of thickness, they are shown on a separate graph.

For the control trial, the 5/8-in. category is the largest for the 6x6 cants, edgings, and the mixed furnish. The 3/8-in. category is the largest for both the slabs and trim blocks. For the 30 degree knife angle (Figure 4.2), the 5/8-in. category was the largest for all five material types. In the higher knife angles (Figures 4.3 and 4.4), there appears to be a slight shift of the peaks to the 3/8-in. category. At a knife angle of 32 degrees, the 3/8-in. category is the peak for the 6x6 cants, slabs and trim

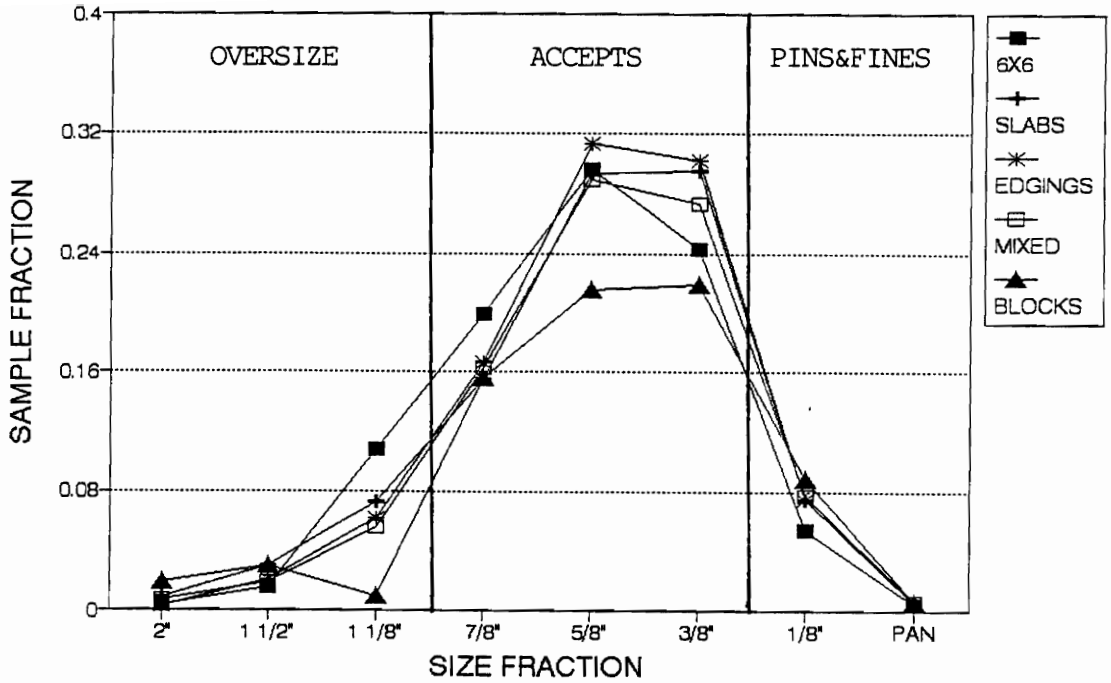

Figure 4.1 - Chip size distribution for the five materials at 31 degree knife angle (control).

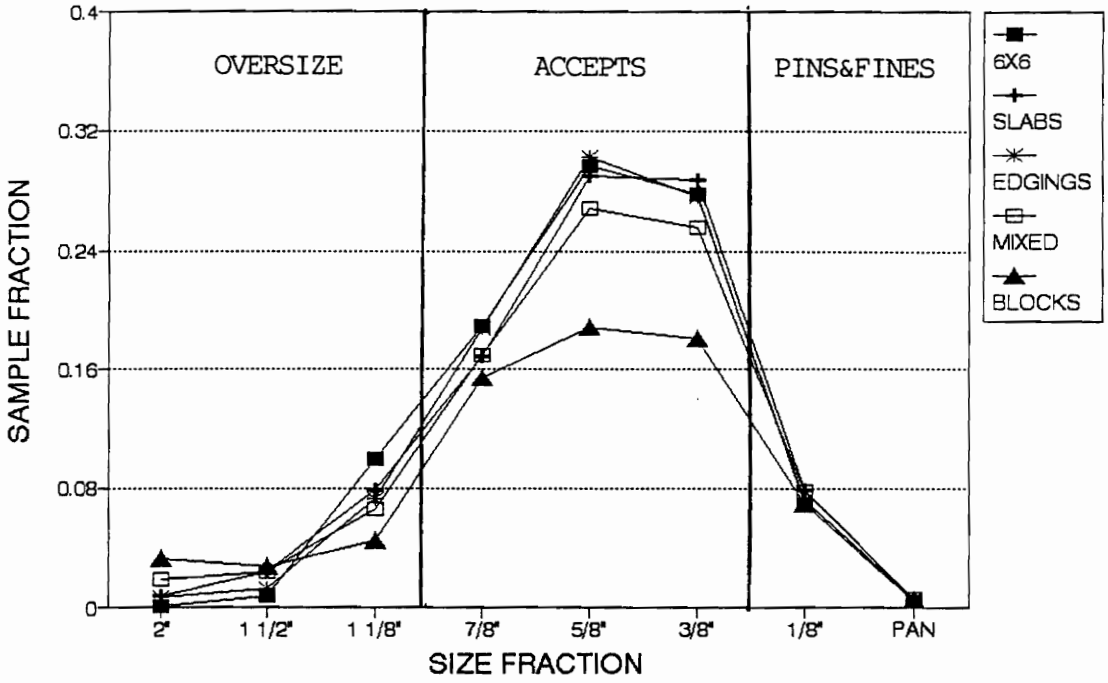

Figure 4.2 - Chip size distribution for the five materials at 30 degree knife angle.

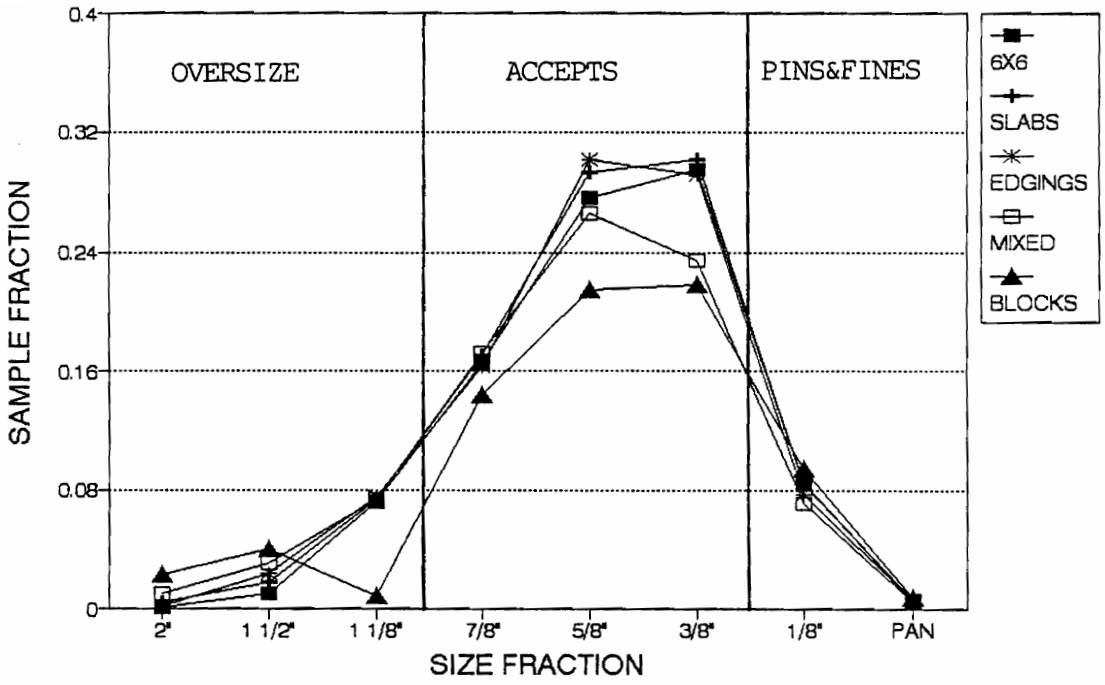

Figure 4.3 - Chip size distribution for the five materials at 32 degree knife angle.

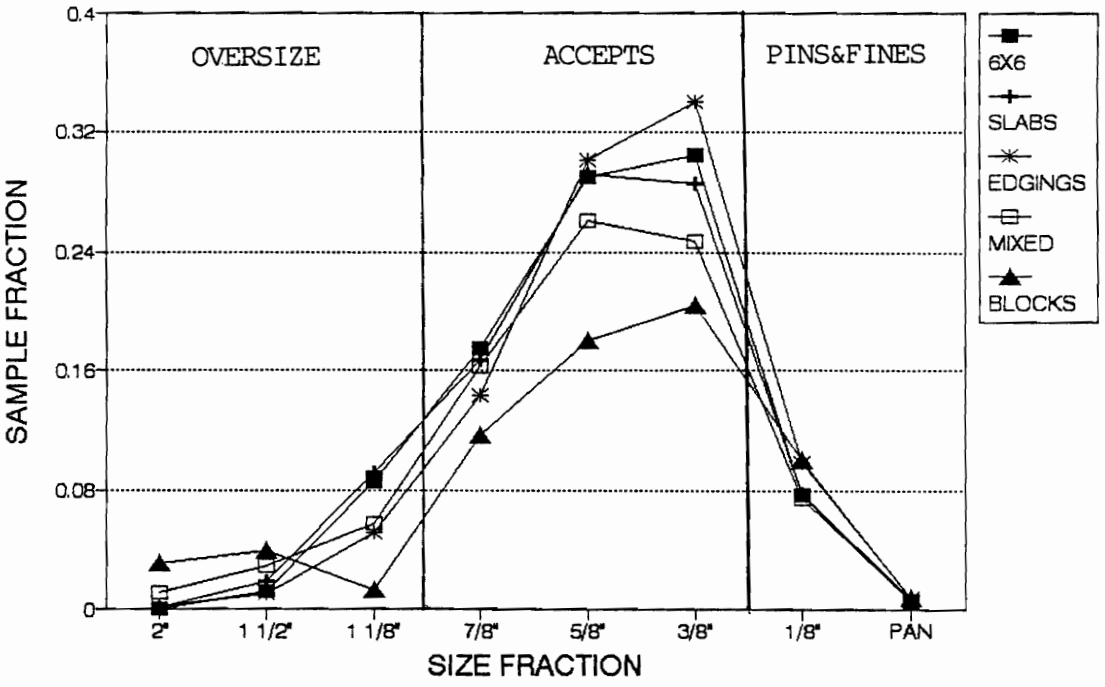

Figure 4.4 - Chip size distribution for the five materials at 33 degree knife angle.

blocks. The 5/8-in. category is the largest for the edgings and mixed furnish. At 33 degrees, the peak for the slabs and the mixed furnish is the 5/8-in. category. The maximum for the 6x6 cants, edgings, and the blocks is the 3/8-in. category.

Overall, there does not appear to be any strong, consistent relationship between knife angle and chip size distribution. Of the 45 two-sample t-tests performed on the nine size fractions for the five material types of the 30 degree knife angle trial, only 12 failed to accept the null hypothesis (11 at the 95% significance level) (Table 4.2). The results of the 32 degree angle trial were similar, with 14 of the 45 tests rejecting the null hypothesis (10 at the 95% significance level).

The 33 degree knife angle showed the greatest difference from the control with 24 of the 45 tests rejecting the null hypothesis. One-half of those tests rejected the null hypothesis at the 99% significance level or higher, indicating a significant difference from the control. While the majority of the tests rejected the null hypothesis, there does not appear to be a strong or consistent trend in the differences. The rejected tests were spread out evenly among the nine size classes (Table 4.2).

Table 4.2 - P-level for two-sample comparison of the three knife angles and the control.

Trial	Material	8 mm	2"	1-1/2"	1-1/8"	7/8"	5/8"	3/8"	1/8"	PAN
30 DEG. ANGLE	CANTS			**				**		
	SLABS					**				
	EDGINGS			*		**				
	MIXED	*	***				**			
	BLOCKS		**		**		***	***	***	
32 DEG. ANGLE	CANTS					**	*	*	**	
	SLABS	*	***	**		**				**
	EDGINGS				*					
	MIXED			***			**	***		
	BLOCKS			**						*
33 DEG. ANGLE	CANTS	*	**			****		****	***	
	SLABS		****	**	*	**				***
	EDGINGS			**		***	*	***	****	****
	MIXED	**	*	**			****	*		
	BLOCKS	*	**	**		****	***			*

LEGEND

SYMBOL	P-VALUE		S. L.
*	(10%	0.100)	90%
**	(5%	0.050)	95%
***	(1%	0.010)	99%
****	(.1%	0.001)	99.9%

Overthicks

The production of overthick chips from all five material types does not appear to be significantly affected by knife angle (Table 4.2). For the 30 and 32 degree angle trials, there were no tests rejecting the null hypothesis at the 95% significance level or higher. Two tests, the mixed furnish in the 30 degree trial and the slabs in the 32 degree trial rejected the null hypothesis at the 90% level, indicating only a slight difference. The 33 degree trial had one test (mixed furnish) reject the null hypothesis at the 95% significance level. The 6x6 cant and trim block material types rejected the null hypothesis at the 90% significance level. There is no consistent relationship between knife angle and the production of overthick chips (Figure 4.5).

Pins and Fines

The percentage of pins and fines produced as a function of knife angle was relatively consistent in all five material types. A positive relationship between knife angle and the production of pins and fines in the 6x6 cants, slabs, edgings, and trim blocks is depicted in Figure 4.6. The mixed furnish appears to have an inverse relationship between knife angle and pins and fines production. The edgings and trim blocks show a consistent, positive

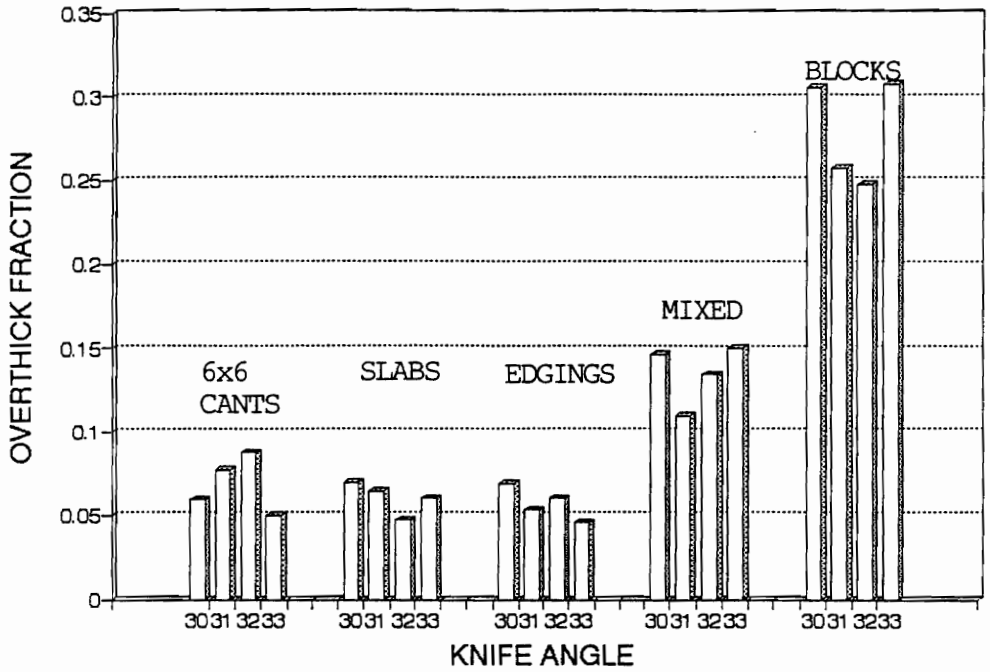

Figure 4.5 - Overthick fraction as a function of knife angle for the five materials.

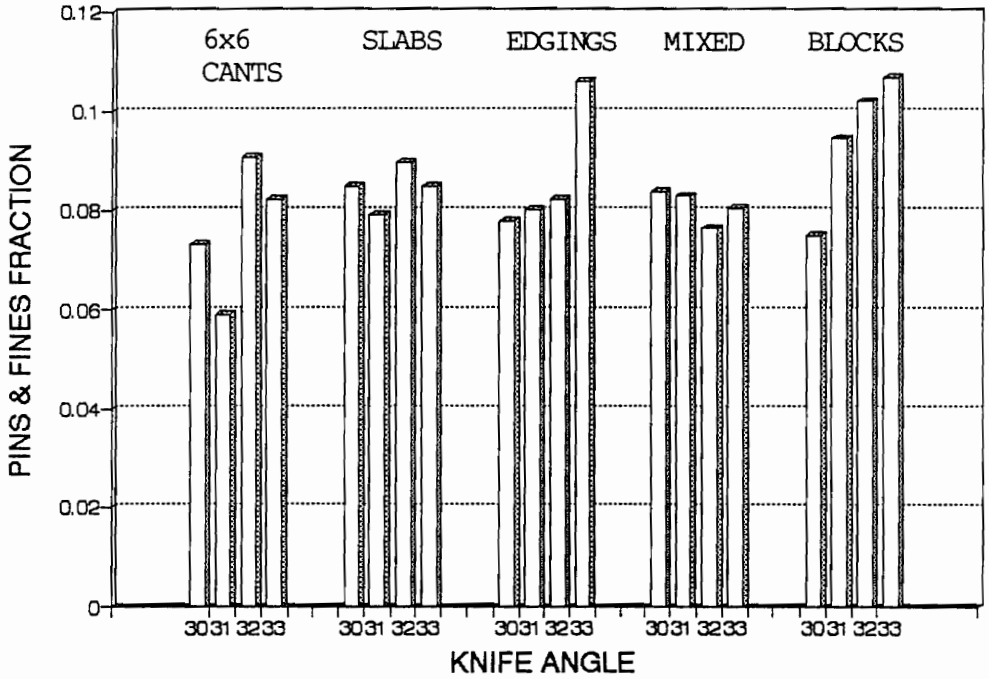

Figure 4.6 - Pins and fines fraction as a function of knife angle for the five materials.

relationship with the pins and fines increasing with each degree increase in knife angle. The 6x6 cants and slabs show a slightly positive relationship, but not as consistent or pronounced as that shown by the edgings and trim blocks. The mixed furnish shows a fairly consistent inverse relationship.

Of the 30 two-sample t-tests performed on the pins and fines fractions, only seven rejected the null hypothesis of no difference at the 95% level or above (Table 4.2). The edgings at a knife angle of 33 degrees showed the biggest difference from the control angle of 31 degrees. The average percentage of pins and fines produced from edgings increased from 8.02% at 31 degrees to 10.59% at 33 degrees, a difference of 2.57%.

Pulpable Chips

The definition of acceptable chips as previously described is those chips less than 1-1/8-in. in length and width and greater than 3/8-in. in length and width. Since all wood chips are pulpable regardless of size (some sizes pulping more easily and producing better quality pulp than others), a broader category of desirable chips must be defined. Pulpable chips are defined as those chips falling into the oversize and acceptable chip categories as previously described. Unacceptable chips are defined as

overthick chips (greater than 8mm thick) and the pins and fines (less than 3/8-in. in length and width). Since most mills will pulp everything that does not fit into the unacceptable chip category, the distinction between pulpable and unacceptable chips has been made. Also, since one of the purposes of this study was to increase the amount of pulpable chips, the presentation of the results will be easier using these classifications.

The results from the knife angle trials do not show any clear, consistent trends in the production of pulpable chips from cants. The amount of pulpable chips from cants dropped sharply from 86.40% at an angle of 31 degrees (control) to 82.17% at 32 degrees, a difference of 4.23% (Figure 4.7). This in part can be attributed to a sudden drop of 4.23% in the oversize portion of the pulpable chips, and a sudden rise of 3.19% in the production of pins and fines (Figure 4.8). The results from the slabs were more consistent, but with an opposite effect on the pulpable chips. The pulpable chips increased by .72% from those of the control angle (Figure 4.9). The amount of accepts increased by 2.27% with a corresponding decrease in oversize chips of 1.56% (Figure 4.10). Thus, the 32 degree knife angle produced more acceptable chips and less oversize chips. The overthicks also decreased by 1.76%. The results from the 30 and 33 degree knife angles were similar to those of the control.

The edgings showed an increase in accepts of 1.46% and

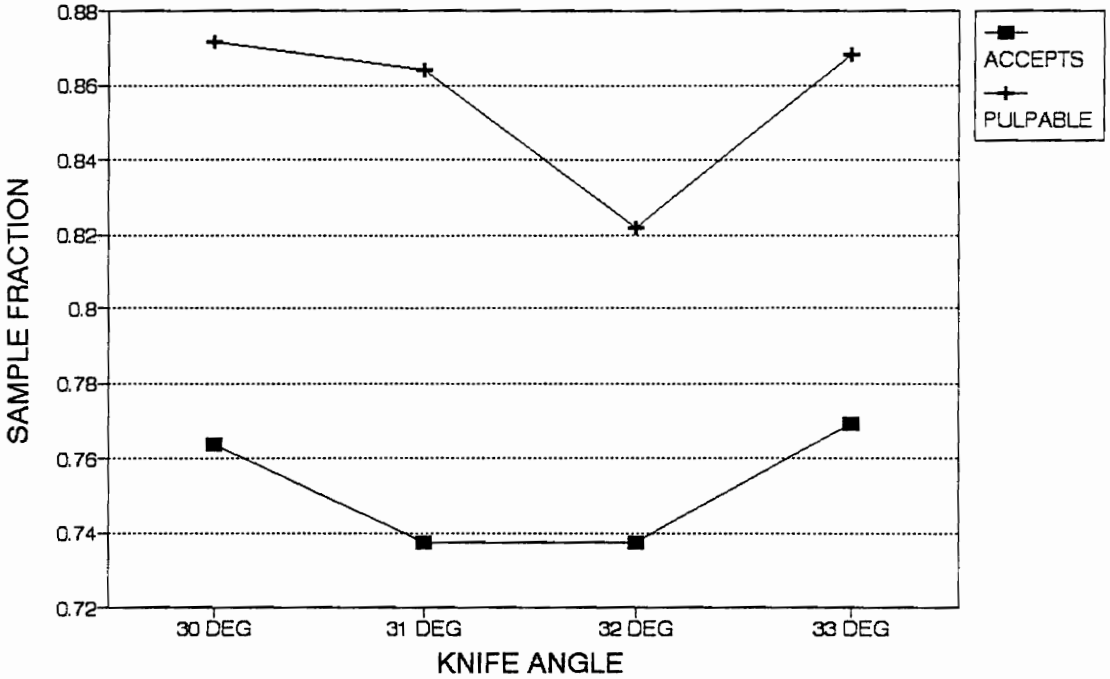

Figure 4.7 - Pulpable and acceptable chips vs. knife angle from cants.

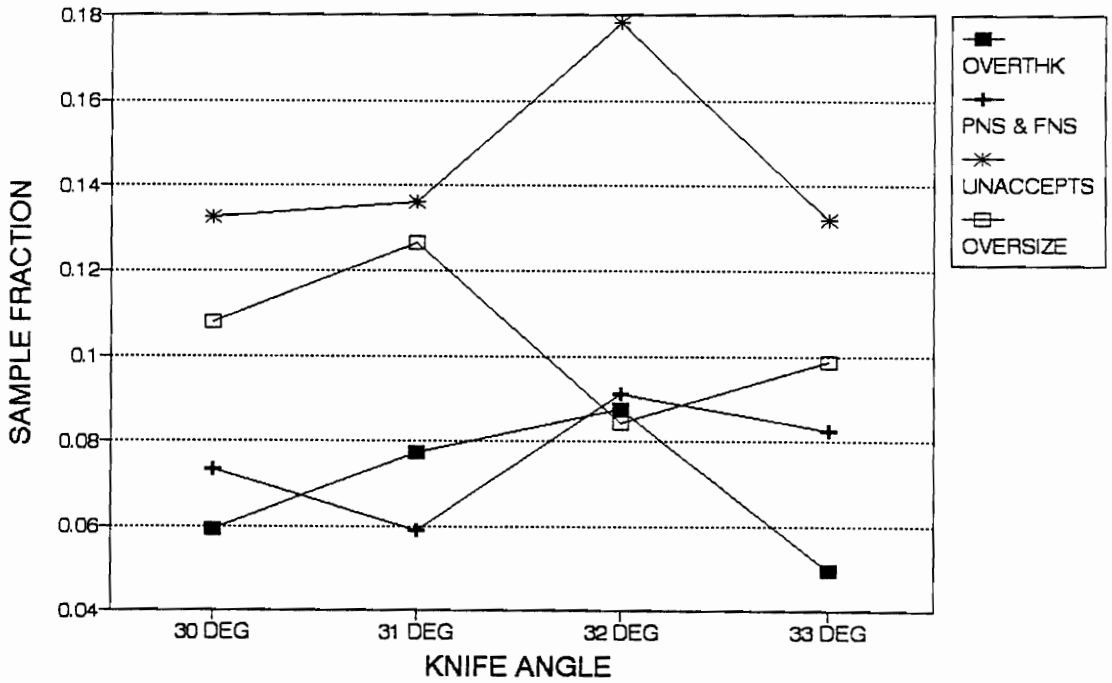

Figure 4.8 - Overthick, oversize, pins and fines, and unacceptable chips vs. knife angle from cants.

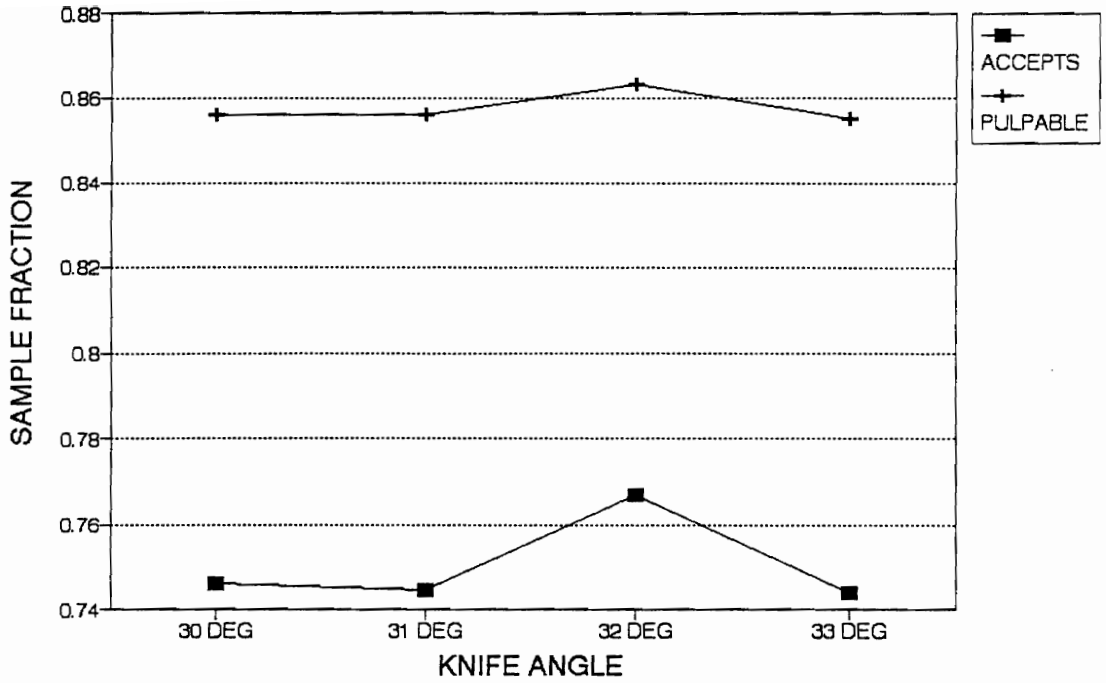

Figure 4.9 - Pulpable and acceptable chips vs. knife angle from slabs.

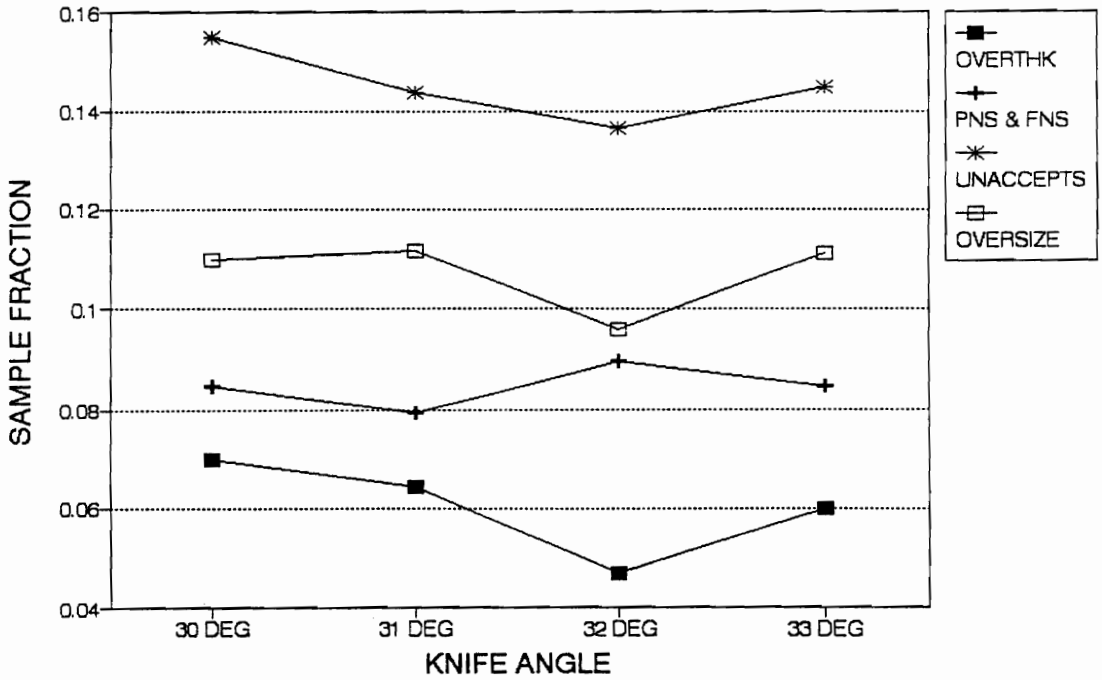

Figure 4.10 - Overthick, oversize, pins and fines, and unacceptable chips vs. knife angle from slabs.

an increase in pulpable chips of .76% from the 30 degrees to 31 degrees (Figure 4.11). As with the cants, the accepts decreased at the angle of 32 degrees, then increased when the angle was increased to 33 degrees. However, the total amount of pulpable chips declined at 32 degrees and again at 33 degrees. This can be attributed to an increase in pins and fines over the same angles (Figure 4.12).

The mixed furnish showed a general decrease in pulpable chips as knife angle increased. The manufacturer's recommended angle of 31 degrees produced the greatest amount of pulpable chips, but that amount decreased by 1.81% at 32 degrees and another 1.97% at 33 degrees (Figure 4.13). The sharp decrease (5.27%) of accepts from 31 degrees to 32 degrees is caused in part by a sharp increase (2.48%) of overthicks over those same angles (Figure 4.14). The increase in overthicks coupled with a 3.45% increase in oversize chips indicates a general shift to larger chips as knife angle increases (Figure 4.14). A sharp increase in accepts from 30 degrees to 31 degrees is offset by a sharp decrease in oversized chips. Thus, there is only a slight increase in pulpable chips over those angles.

The trim blocks show the greatest differences in chip sizes produced by the different knife angles. Figure 4.15 clearly shows that knife angles of 31 and 32 degrees produce the most pulpable chips with sharp decreases in both accepts and pulpable (7.46% and 6.51% respectively) when changing to

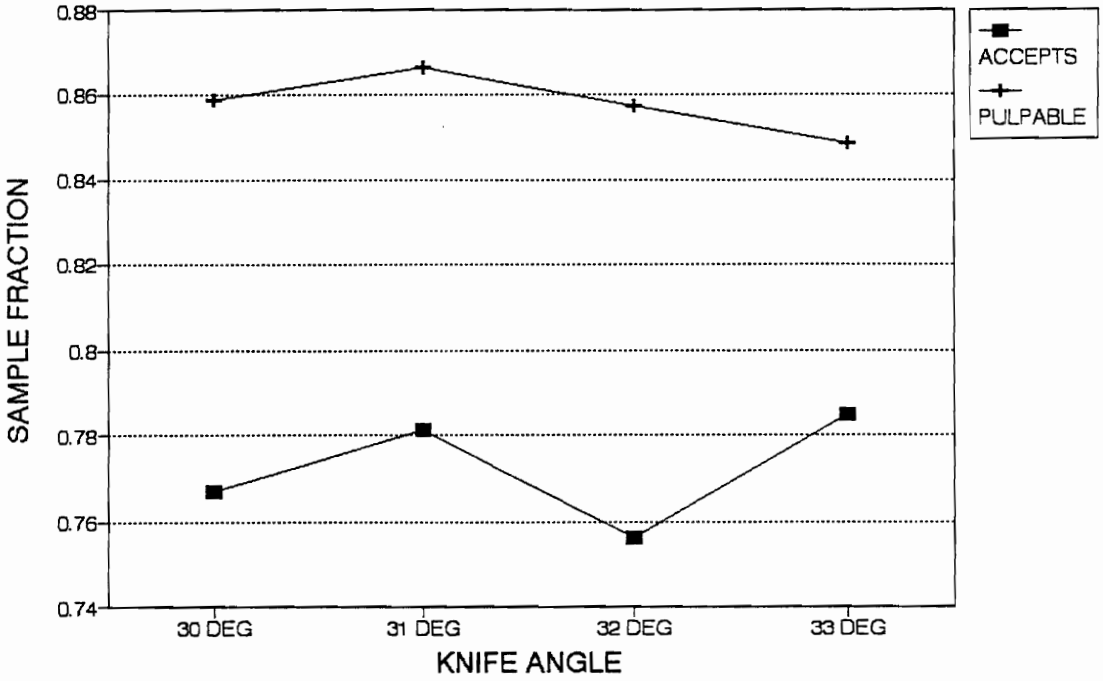

Figure 4.11 - Pulpable and acceptable chips vs. knife angle from edgings.

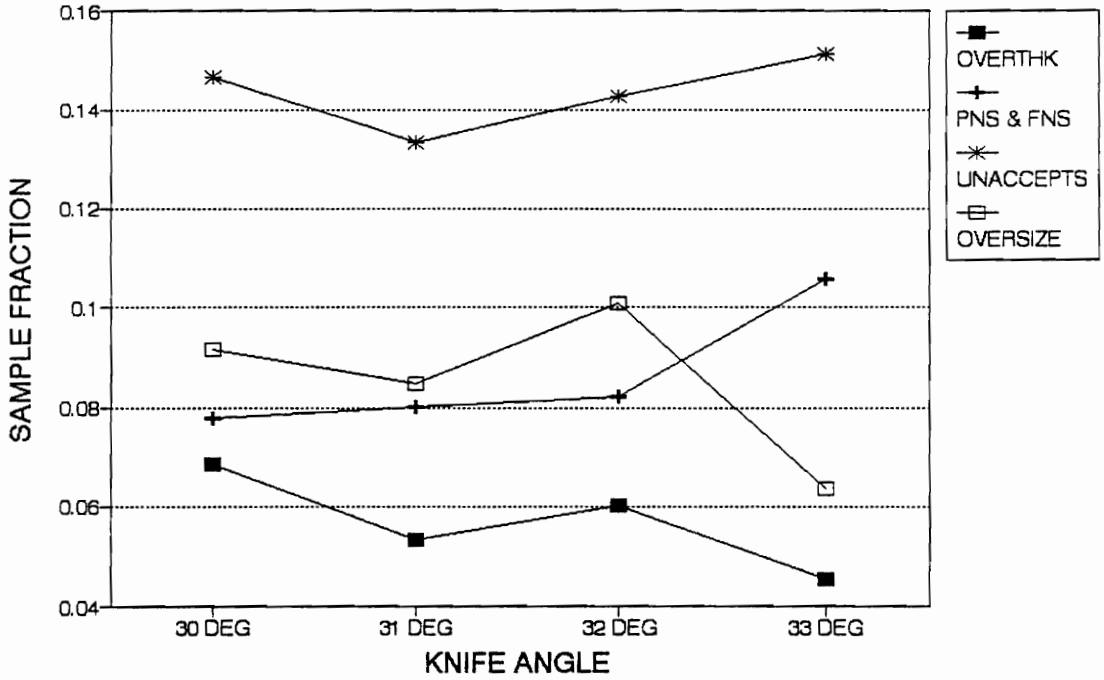

Figure 4.12 - Overthick, oversize, pins and fines, and unacceptable chips vs. knife angle from edgings.

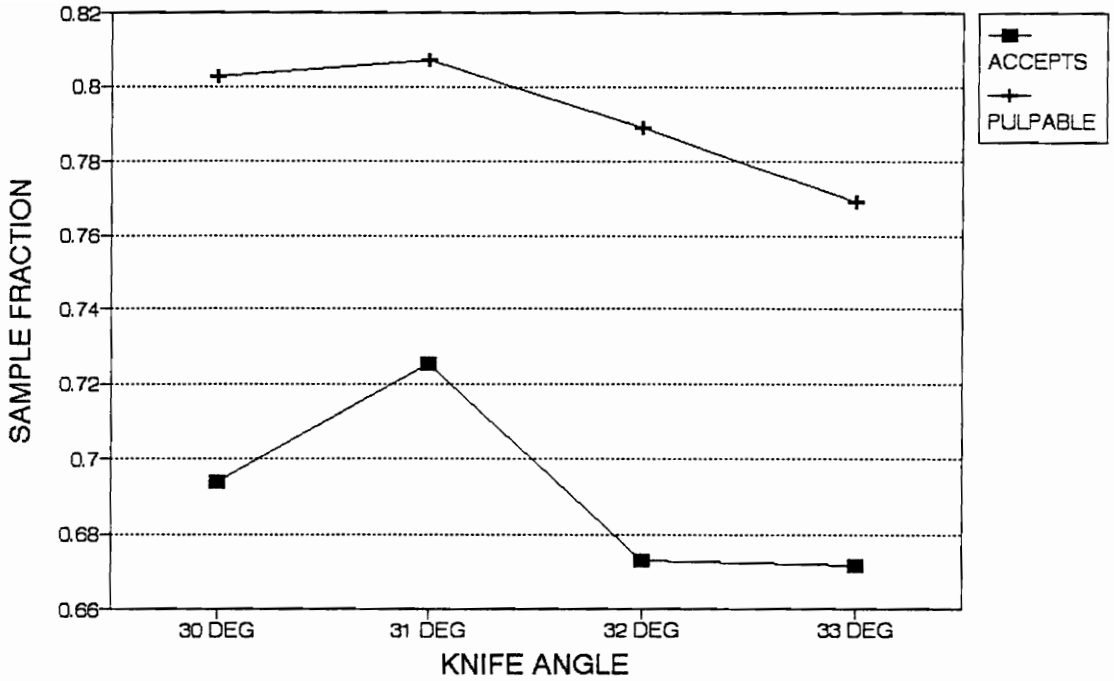

Figure 4.13 - Pulpable and acceptable chips vs. knife angle from mixed furnish.

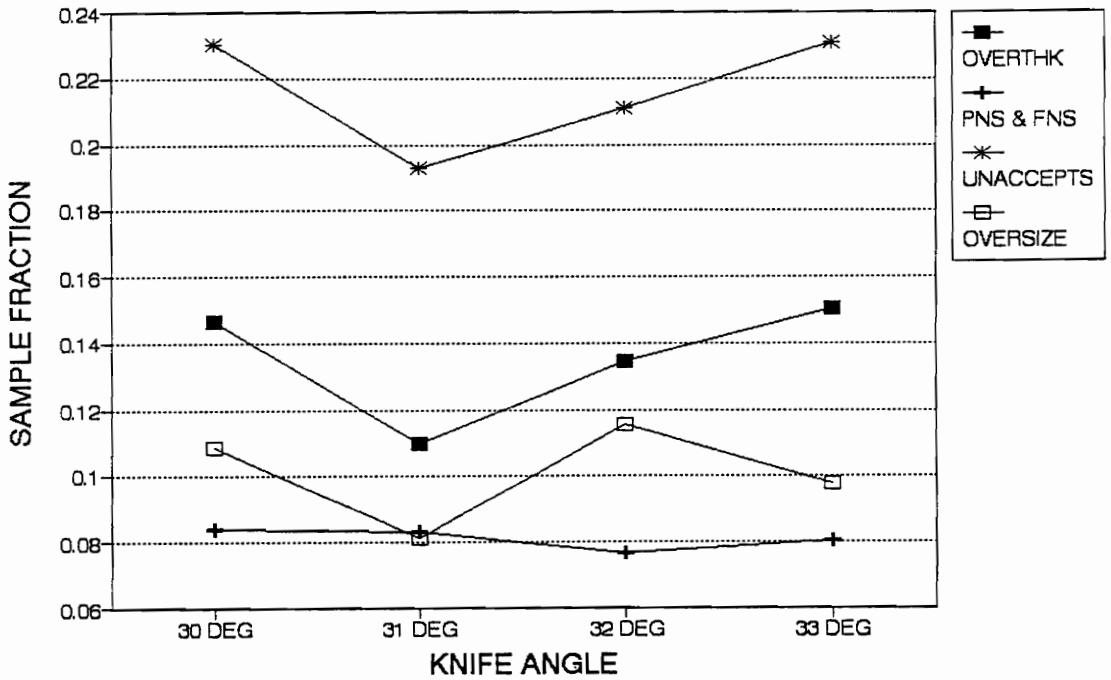

Figure 4.14 - Overthick, oversize, pins and fines, and unacceptable chips vs. knife angle from mixed furnish.

33 degrees. A sharp increase (6.03%) in overthicks and an increase in pins and fines caused the decrease in pulpable chips at 33 degrees (Figure 4.16).

Table 4.2 lists the statistical significances between the three test angles and the 31 degree control.

EFFECT OF TEMPERATURE ON CHIP SIZE DISTRIBUTION

The wood used for the temperature trials was placed in a refrigerated van set at 20 deg. F (-7 deg. C) for several days before the trials were run. The frozen wood was brought to a temperature of -4 deg. C, and the chilled wood was brought to a temperature of +2 deg. C. A temperature probe was used to determine the temperature of each bundle of material before it was chipped to confirm that it was at the desired temperature.

The control trial served as the ambient temperature trial [95 deg. F (35 deg. C)]. The largest size category was the 5/8-in. class for the cants, edgings, and the mixed furnish (Figure 4.17). The 3/8-in. size category was the largest for the slabs and the trim blocks.

Under chilled conditions, the size distributions of all five material types shifted toward the smaller size fractions (Figure 4.18). The largest size category for all five material types was 3/8-in. The 1/8-in. size category was noticeably larger than the same category under ambient

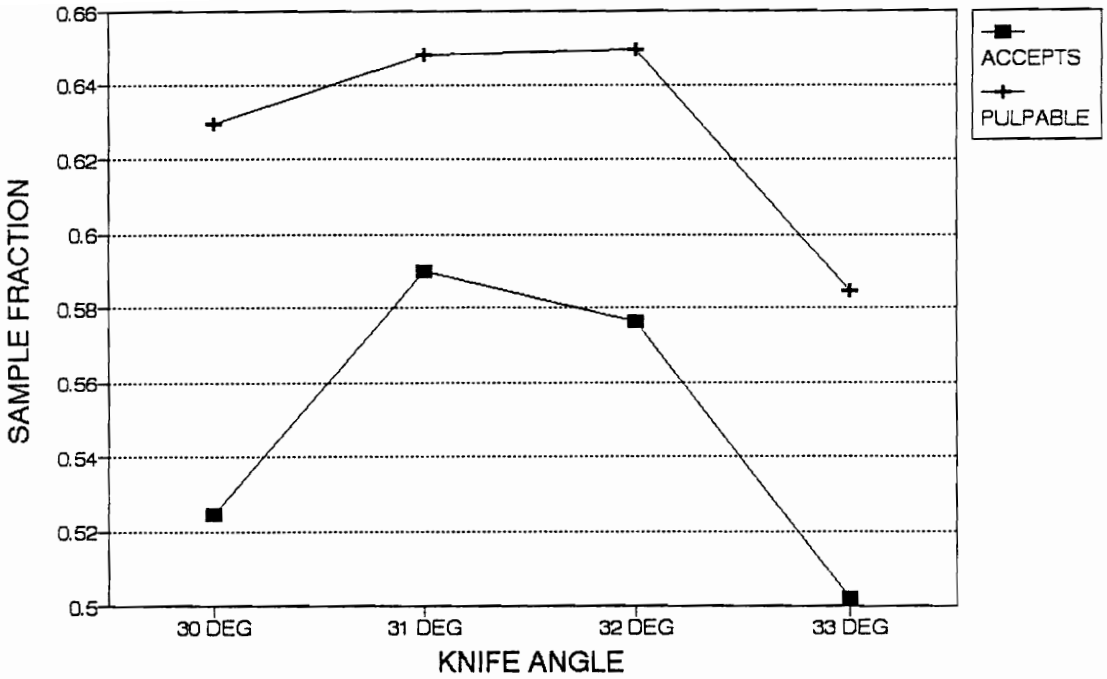

Figure 4.15 - Pulpable and acceptable chips vs. knife angle from trim blocks.

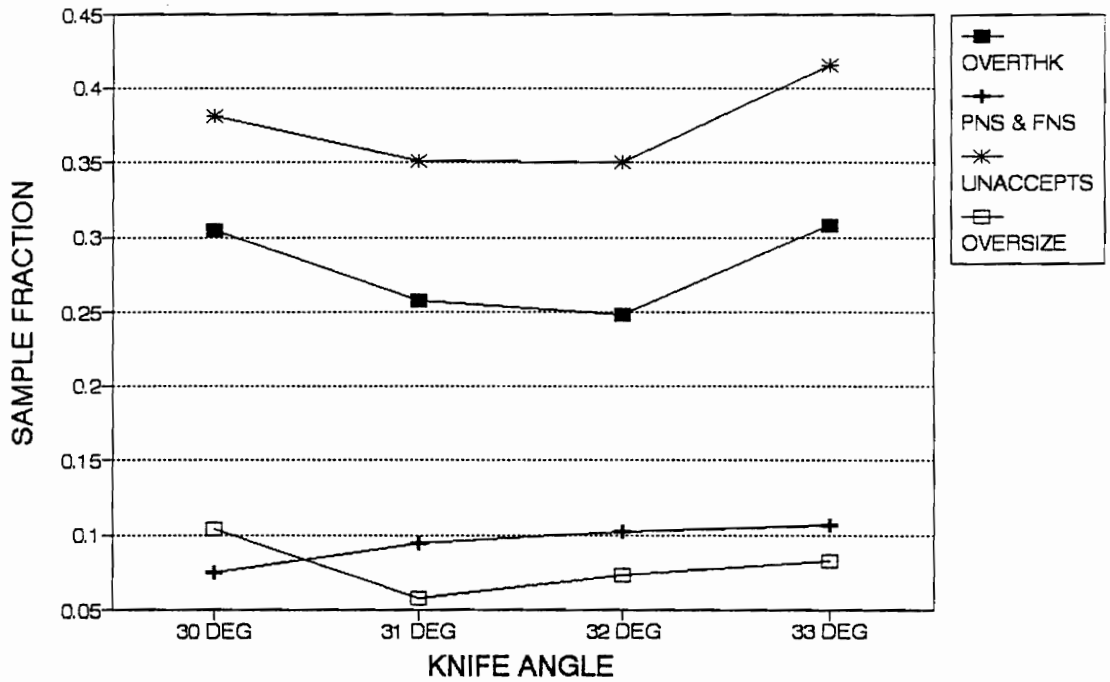

Figure 4.16 - Overthick, oversize, pins and fines, and unacceptable chips vs. knife angle from trim blocks.

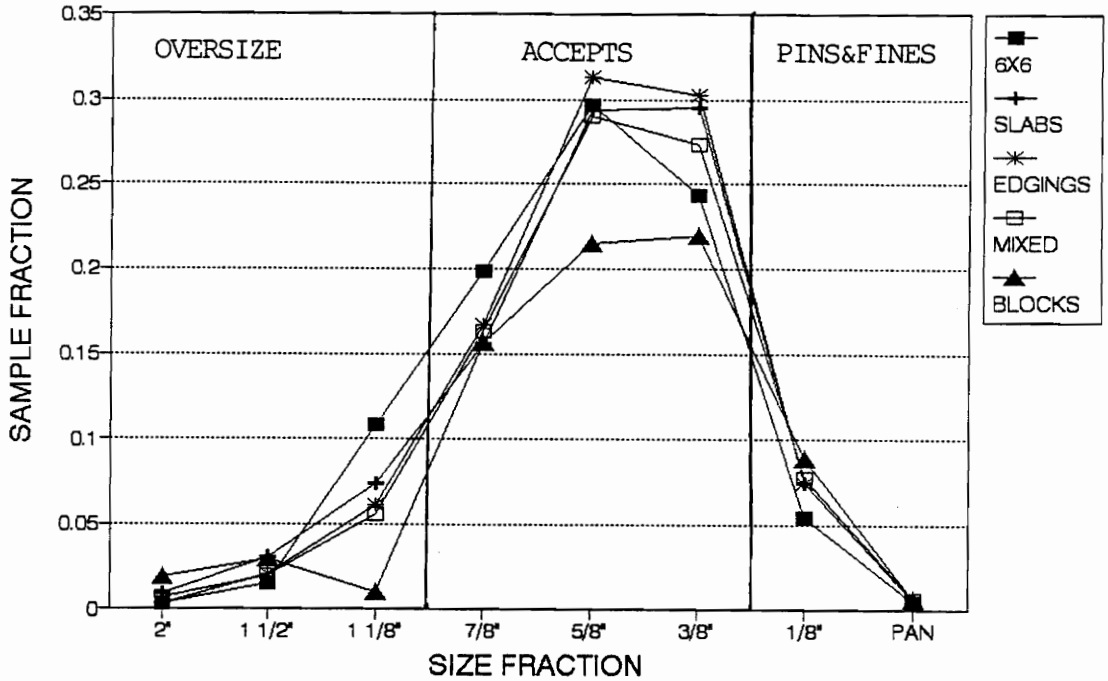

Figure 4.17 - Chip size distribution for the five materials at ambient temperature.

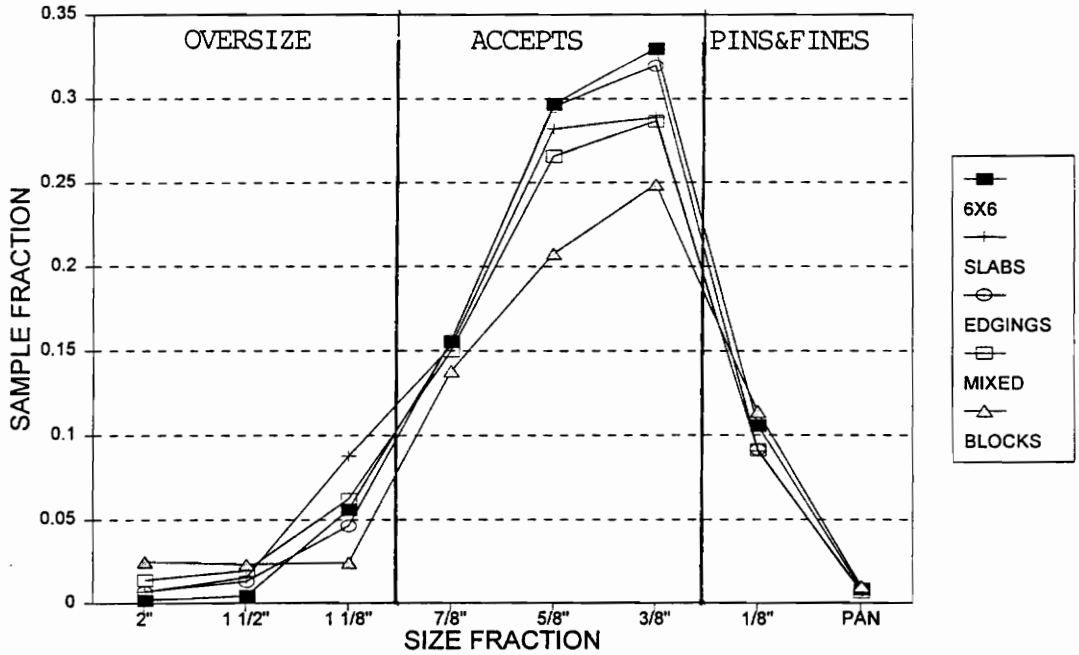

Figure 4.18 - Chip size distribution for the five materials at chilled temperature.

conditions. Eight of the 10 two-tailed, two-sample t-tests performed on the 1/8-in. and fine size classes rejected the null hypothesis that the means of the ambient and chilled material were equal at the 95% significance level (Table 4.3). One test rejected the null hypothesis at the 90% significance level. Of the 45 total tests performed on all material types and size fractions, 24 rejected the null hypothesis of no difference between the means.

Under frozen conditions, the size distributions for all five material types also exhibited a shift to the smaller size classes as compared to the ambient temperature trial, but not to the same extent as that exhibited by the chilled trials (Figure 4.19). The peak of the chip distribution for the cants shifted back to the 5/8-in. category. The peak for all of the other material types was the 3/8-in. category. Of the 45 two-tailed, two-sample t-tests performed on the nine size classes of the five material types, 18 failed to reject the null hypothesis of no difference between the means at the 95% significance level or higher (Table 4.3). All of the tests performed on the 1/8-in. and fine size classes rejected the null hypothesis at the 95% significance level or higher.

Overthicks

The amount of overthick chips produced exhibited

Table 4.3 - P-level for two-sample comparison of the two test temperatures and the ambient.

Trial	Material	8 mm	2"	1-1/2"	1-1/8"	7/8"	5/8"	3/8"	1/8"	PAN
CHILLED	CANTS	**		****	**	****		****	****	***
	SLABS			***					**	**
	EDGINGS	*	**	*			**		**	***
	MIXED		*			*	**		*	
	BLOCKS					**		*	**	***
FROZEN	CANTS	***	**	***		**	*	****	***	***
	SLABS		****	***			**		***	****
	EDGINGS						****		****	****
	MIXED	**		**		**	****		**	****
	BLOCKS					****	****		****	****

LEGEND

SYMBOL	P-VALUE		S. L.
*	(10%	0.100)	90%
**	(5%	0.050)	95%
***	(1%	0.010)	99%
****	(.1%	0.001)	99.9%

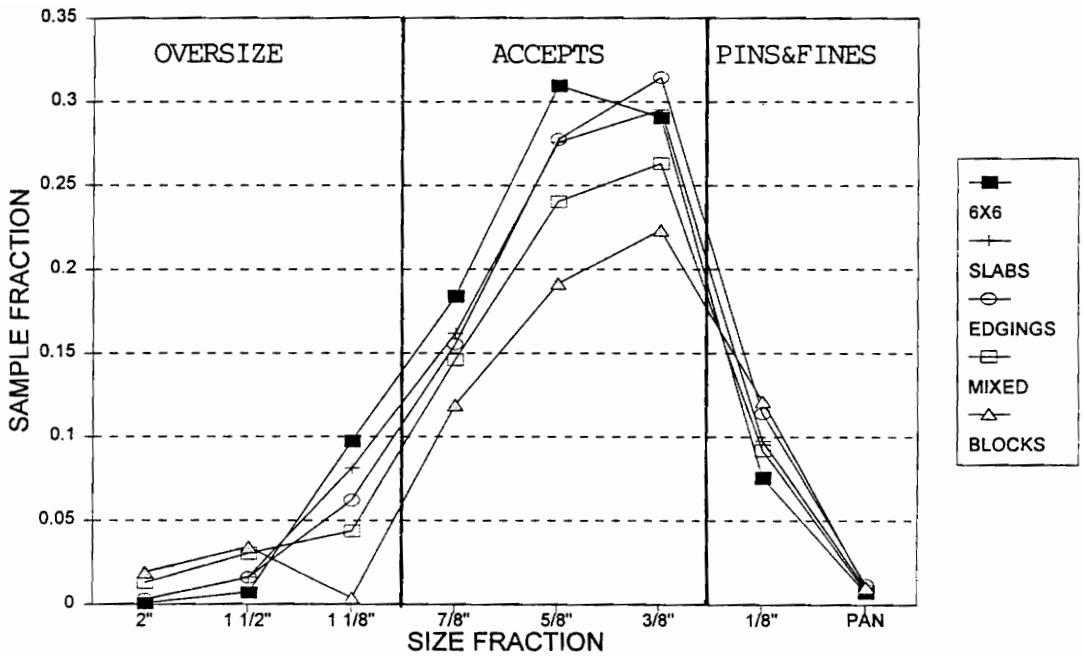

Figure 4.19 - Chip size distribution for the five materials at frozen temperature.

conflicting results between material types. The cants showed a definite linear decrease in the amount of overthick chips produced as the temperature decreased (Figure 4.20). The slabs and edgings showed an overall decrease in overthicks, but this relationship was not linear. The mixed furnish and trim blocks showed a definite increase in overthicks produced (5.29% and 1.94% respectively) as the temperature moved from ambient to frozen. The relationship for both material types was linear.

Pins and Fines

For all five material types, the amount of pins and fines produced as a function of temperature increased with decreasing temperature (Figure 4.21). The slabs, edgings, mixed furnish, and trim blocks produced strong, consistent trends of increasing pins and fines as temperatures decreased. The cants showed a similar, but weaker trend of increasing pins and fines. The amount of pins and fines produced as the temperature of the wood changed from ambient to chilled increased by 5.5%, but then dropped by 3.13% as the temperature changed to below freezing. Eighteen of the 20 two-tailed, two-sample t-tests performed on the five material types rejected at the 95% significance level or higher the null hypothesis that the percentages of pins and fines produced at the two temperatures below ambient were

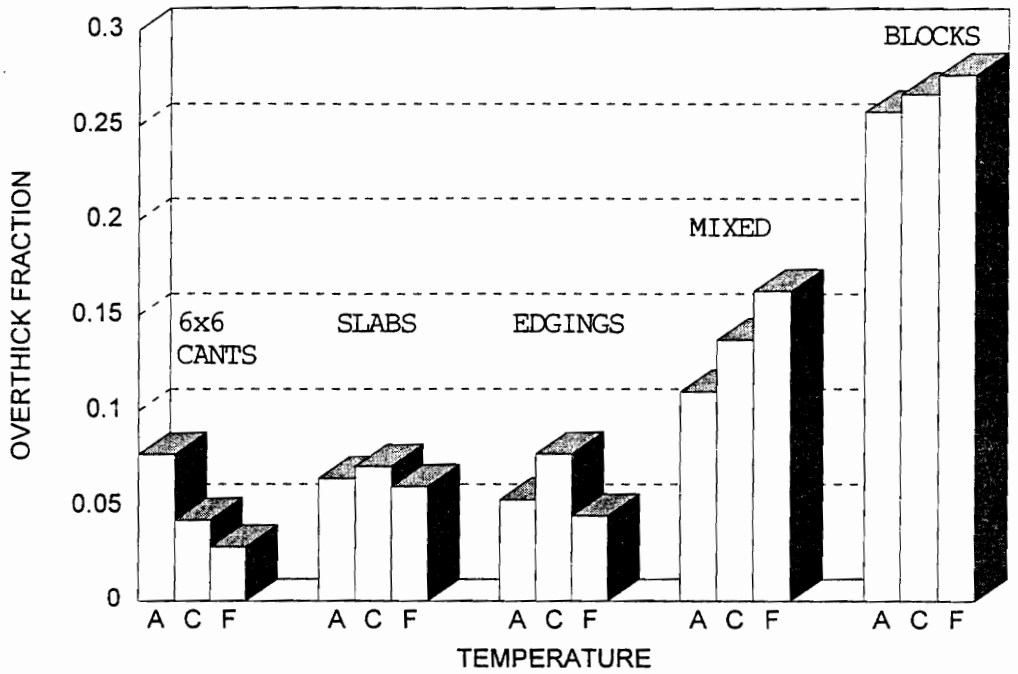

Figure 4.20 - Overthick fraction as a function of temperature for the five materials.

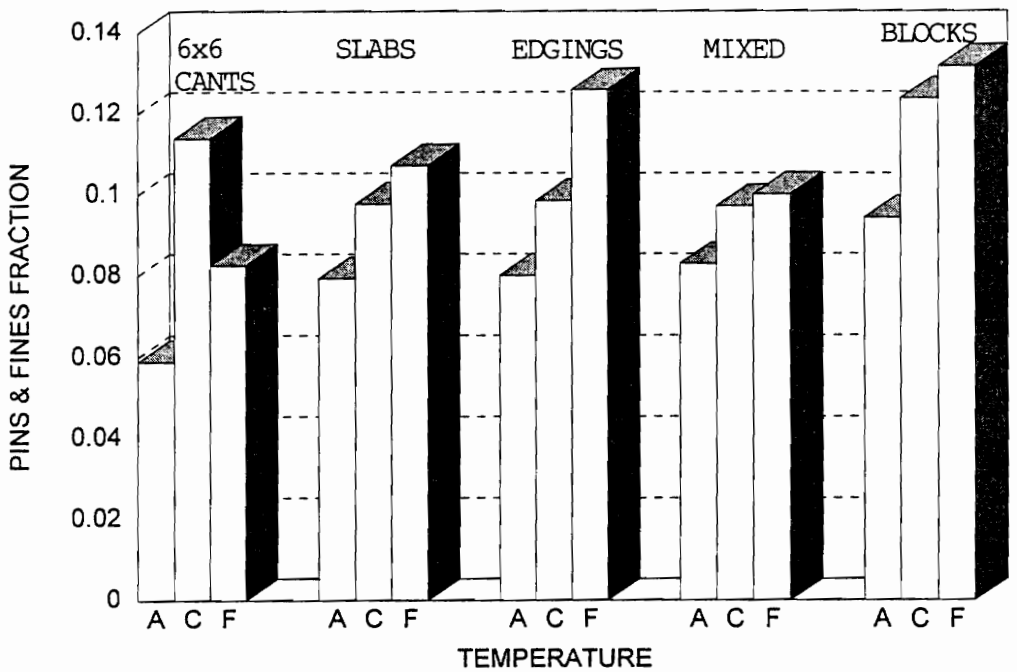

Figure 4.21 - Pins and fines fraction as a function of temperature for the five materials.

equal to that produced at ambient temperature.

Pulpable Chips

The amount of pulpable chips produced from the cants increased with decreasing temperature due to the significant decrease in overthick chips as seen in Figures 4.22 and 4.23. The amount of pulpable chips decreased slightly (1.99%), but then increased sharply by 4.49% between the chilled and frozen trials.

The other four material types showed a decrease in pulpable chips as the temperature decreased (Figures 4.24, 4.26, 4.28, 4.30). The significant increase in pins and fines produced from slabs and edgings nullified any significant decrease in overthick chips, thus producing the decrease in pulpable chips (Figures 4.25 and 4.27). Figures 4.29 and 4.31 illustrate that increases in both overthicks and pins and fines in the mixed furnish and trim blocks caused a decrease in the pulpable chips obtained from those two material types.

Table 4.3 lists the statistical significances between the two test temperatures and the ambient control temperature.

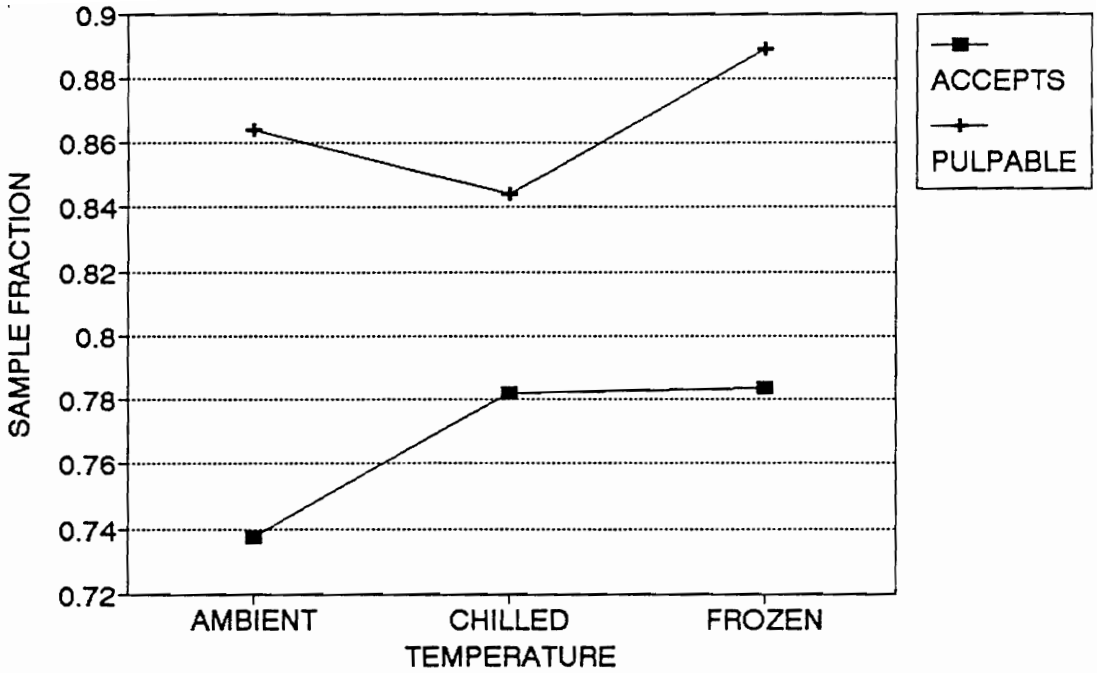

Figure 4.22 - Pulpable and acceptable chips vs. temperature from cants.

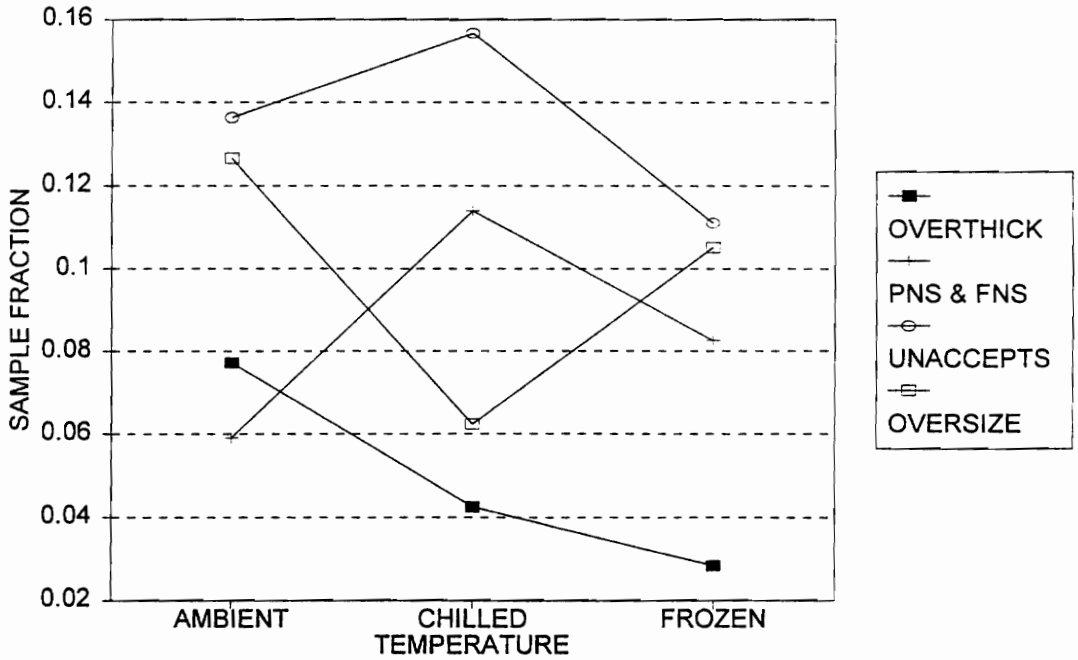

Figure 4.23 - Overthick, oversize, pins and fines, and unacceptable chips vs. temperature from cants.

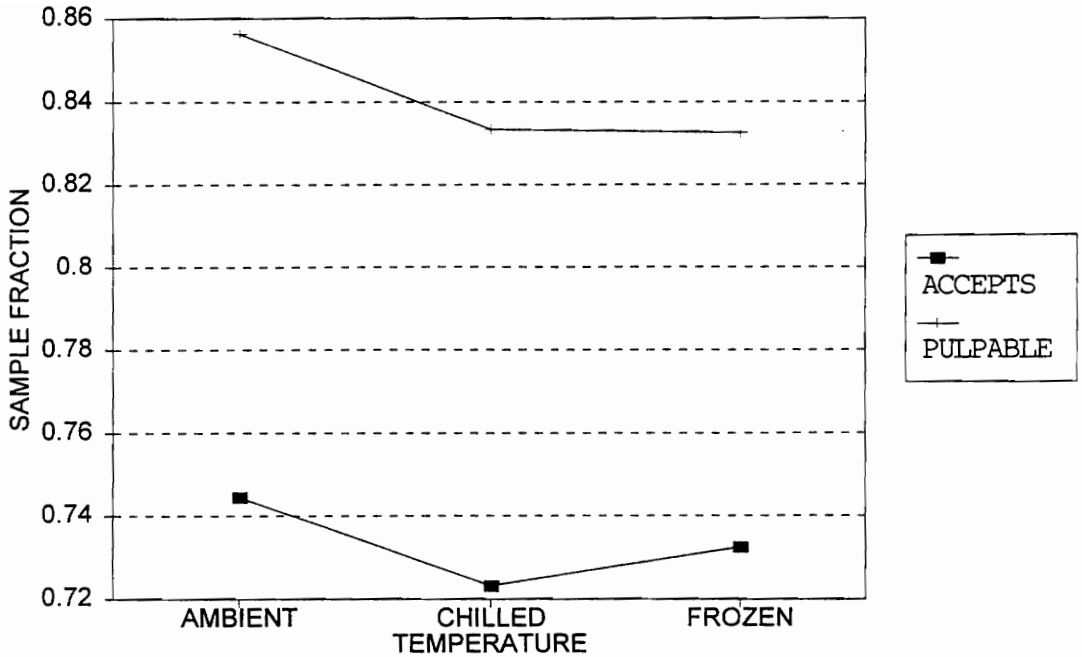

Figure 4.24 - Pulpable and acceptable chips vs. temperature from slabs.

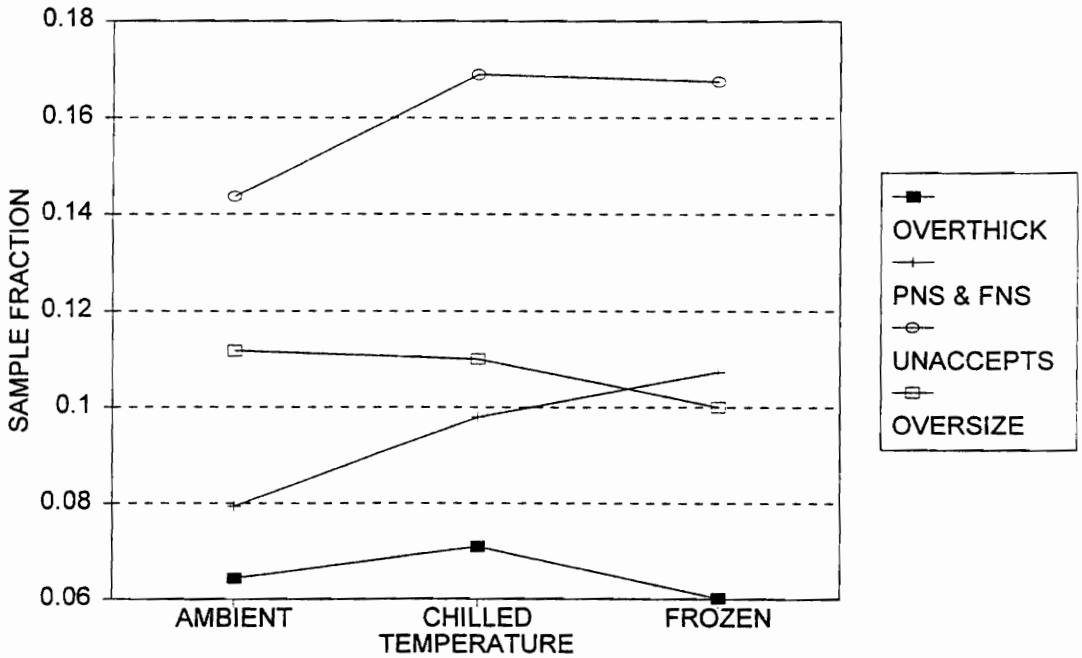

Figure 4.25 - Overthick, oversize, pins and fines, and unacceptable chips vs. temperature from slabs.

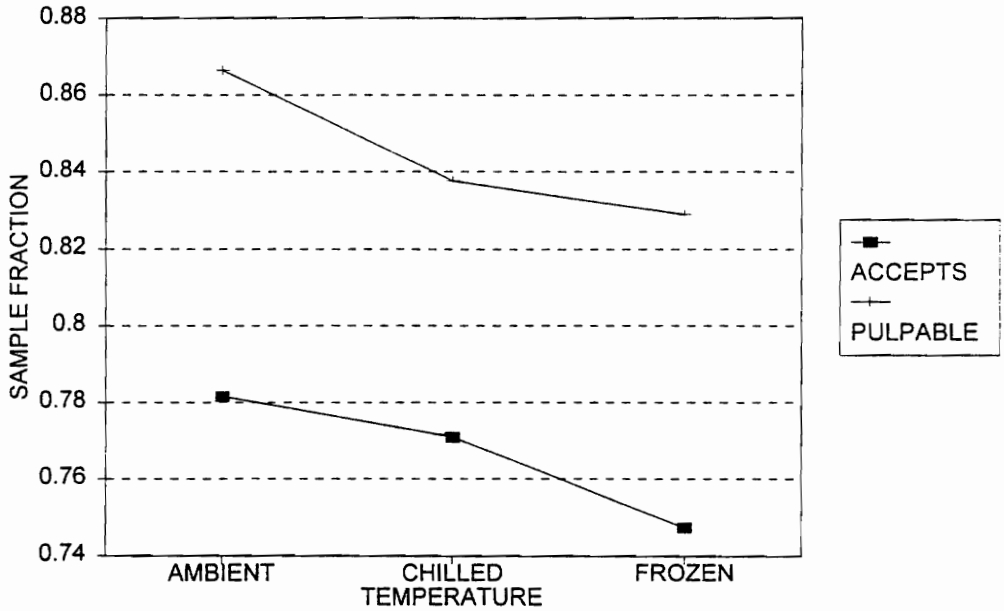

Figure 4.26 - Pulpable and acceptable chips vs. temperature from edgings.

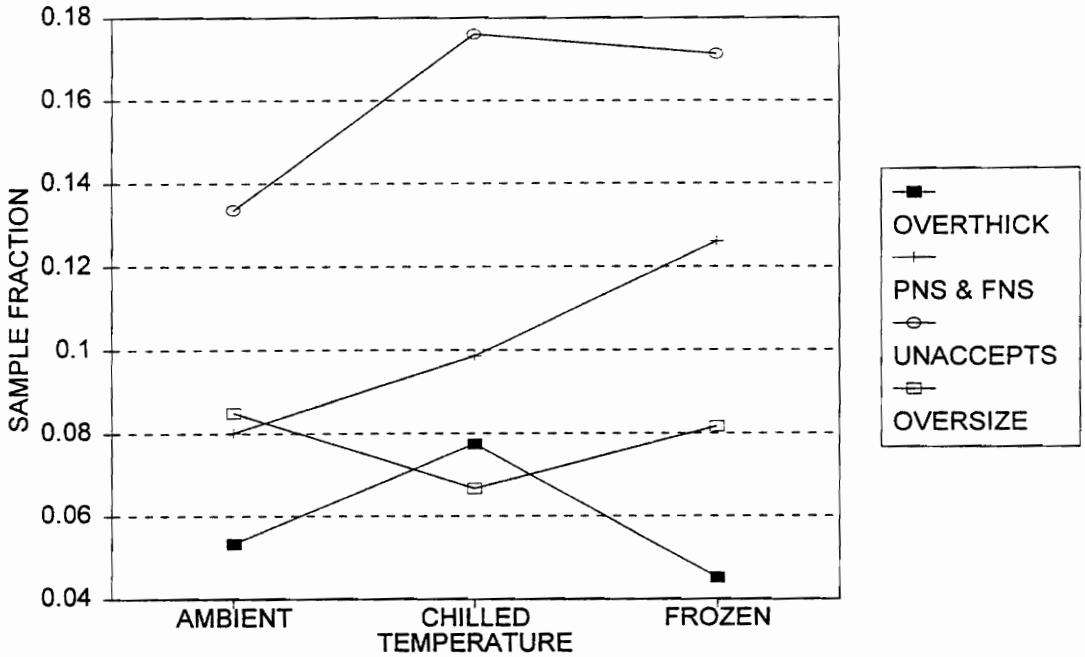

Figure 4.27 - Overthick, oversize, pins and fines, and unacceptable chips vs. temperature from edgings.

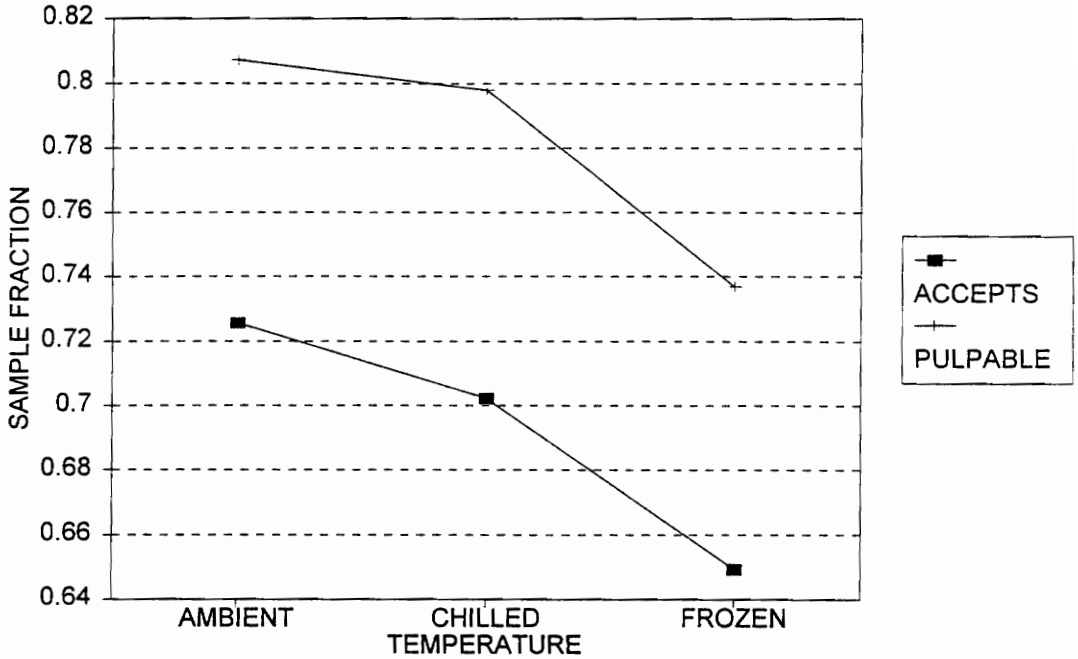

Figure 4.28 - Pulpable and acceptable chips vs. temperature from mixed furnish.

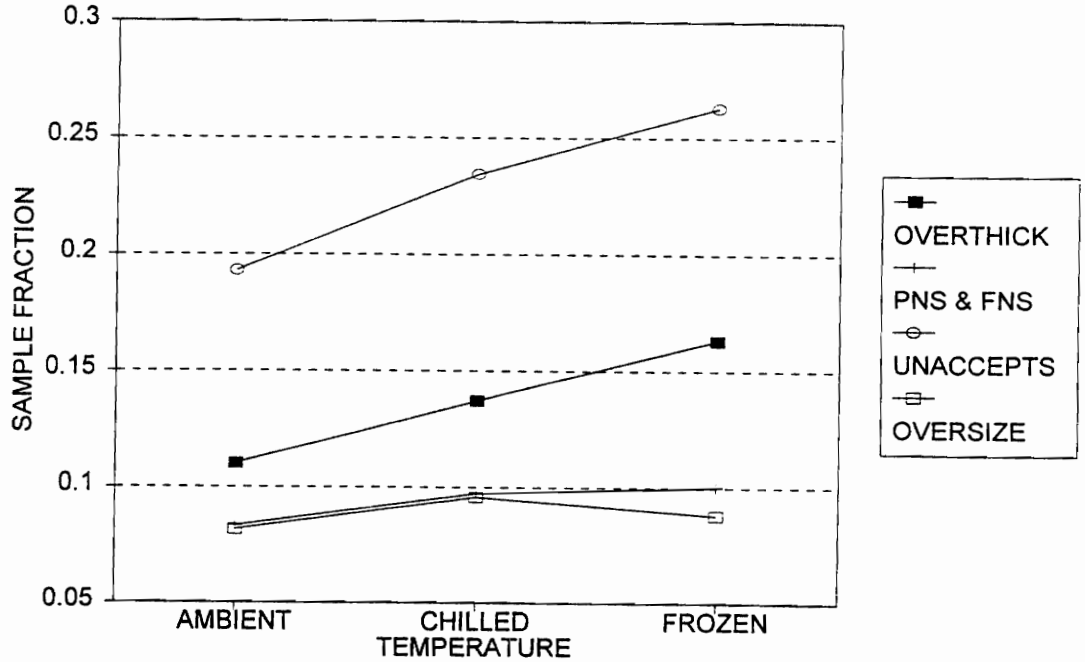

Figure 4.29 - Overthick, oversize, pins and fines, and unacceptable chips vs. temperature from mixed furnish.

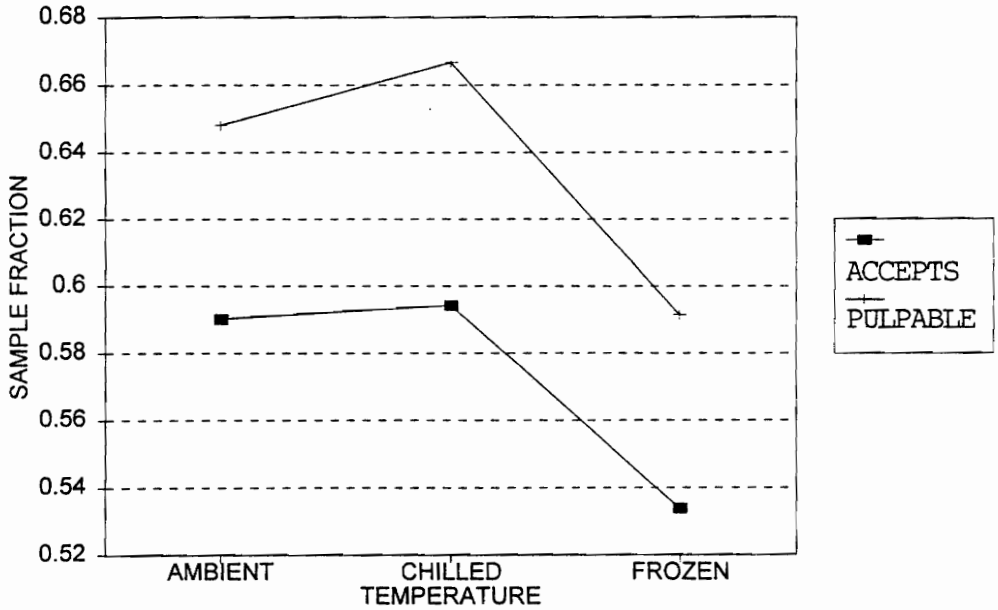

Figure 4.30 - Pulpable and acceptable chips vs. temperature from trim blocks.

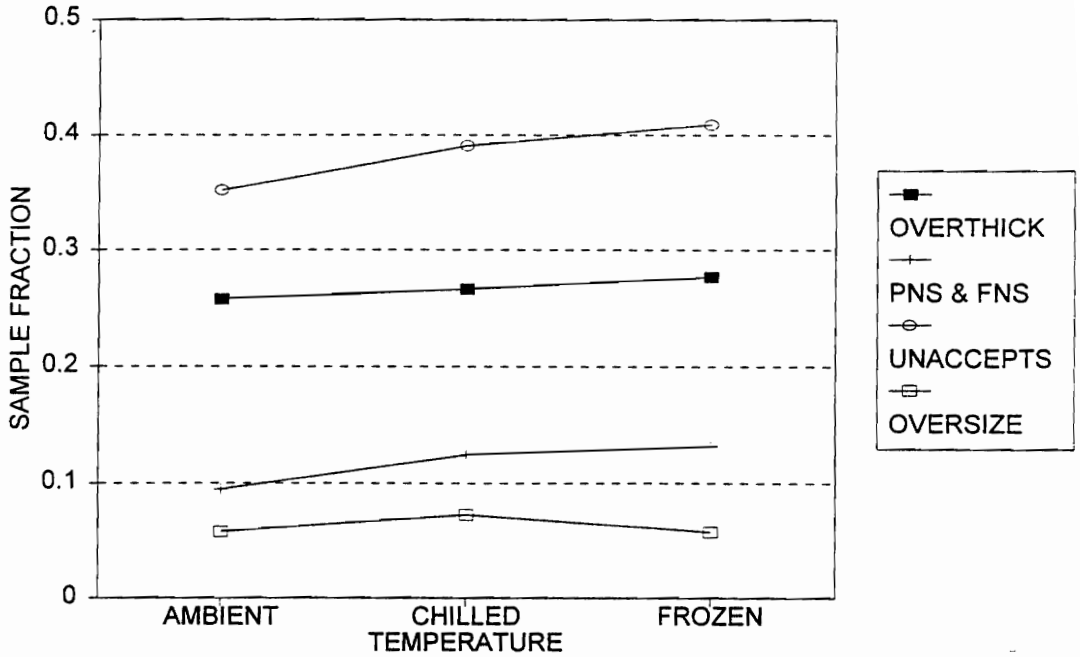

Figure 4.31 - Overthick, oversize, pins and fines, and unacceptable chips vs. temperature from trim blocks.

EFFECT OF DISK SPEED ON CHIP SIZE DISTRIBUTION

The two speeds for the disk speed trials were obtained using the drift down method as previously described. Table 4.4 shows the actual and desired beginning and ending speeds which were obtained during the trials. Each batch of wood was moved to the chipper infeed spout and the vibrating conveyor was stopped. The chipper motor was shut off and the disk was allowed to slow down. When the disk speed was 35.5 rpm (five percent) above the desired test speed, the conveyor was started, allowing the wood to enter the chipper. The theory was that the disk would reach the desired test speed midway through the chipping process and finish chipping each batch at 35.5 rpm (five percent) below the test speed; thus the desired test speed would be the average speed for each batch. Each batch of wood was started at 35.5 rpm above the target speed, but they all finished slower than the intended speed. This was caused in part by the inability to precisely control the chipping process. The material did not always hit the disk at the desired speed, nor did it feed evenly into the chipper. Occasionally a large amount would enter the chipper all at once, causing the disk to slow down more quickly than anticipated. As a result, the midpoints of the chipping processes were approximately 10 percent slower than originally intended. From now on, the results and

discussion will be on the actual test speeds obtained: 70 percent and 50 percent.

The chip size distribution for the 100% disk speed (707 rpm) is shown in Figure 4.32. The 5/8-in. category is the peak for the cants, edgings, and the mixed furnish and the 3/8-in. size class is almost as large . The 3/8-in. category is the peak for the slabs and trim blocks, but there is less than 1% difference between the amounts in the 3/8-in. size class and the 5/8-in. size class for those two material types.

As disk speed decreases, the chip size distribution shifts to the larger size categories as illustrated by Figures 4.33 and 4.34. At 70% disk speed, the 5/8-in. size category remained the largest for the cants, edgings, and the mixed furnish, and the peak for the slabs shifted from the 3/8-in. size class to the 5/8-in. size class. The peak for the mixed furnish is shared by the 7/8-in. and 5/8-in. size classes, with only .14% difference between the two. Even though the largest size class remains relatively unchanged between the 100% disk speed and the 70% disk speed, Figure 4.33 clearly illustrates a definite shift in the overall chip size distribution to the larger size classes. Of the 45 two-tailed, two-sample t-tests performed on the nine size fractions of the five material types at 70% disk speed, 32 rejected the null hypothesis of no difference between the means at the 95% significance level or higher.

Table 4.4 - Desired test speed, target start and finish speeds, actual finishing speeds, and actual average test speeds.

DISK SPEED (rpm)									
DESIRED TEST SPEED	REP #	TARGET START	TARGET FINISH	ACTUAL FINISH SPEED 6X6	SLABS	EDGINGS	MIXED	BLOCKS	ACTUAL AVERAGE TEST SPEED
80% 566 RPM	1	601	530	448	451	459	455	463	528 RPM, 75%
80% 566 RPM	2	601	530	447	470	454	447	419	524 RPM, 74%
80% 566 RPM	3	601	530	456	419	491	440	440	525 RPM, 74%
60% 424 RPM	1	460	389	328	361	343	350	347	403 RPM 57%
60% 424 RPM	2	460	389	307	276	350	300	365	390 RPM 55%
60% 424 RPM	3	460	389	300	362	383	290	301	394 RPM 56%

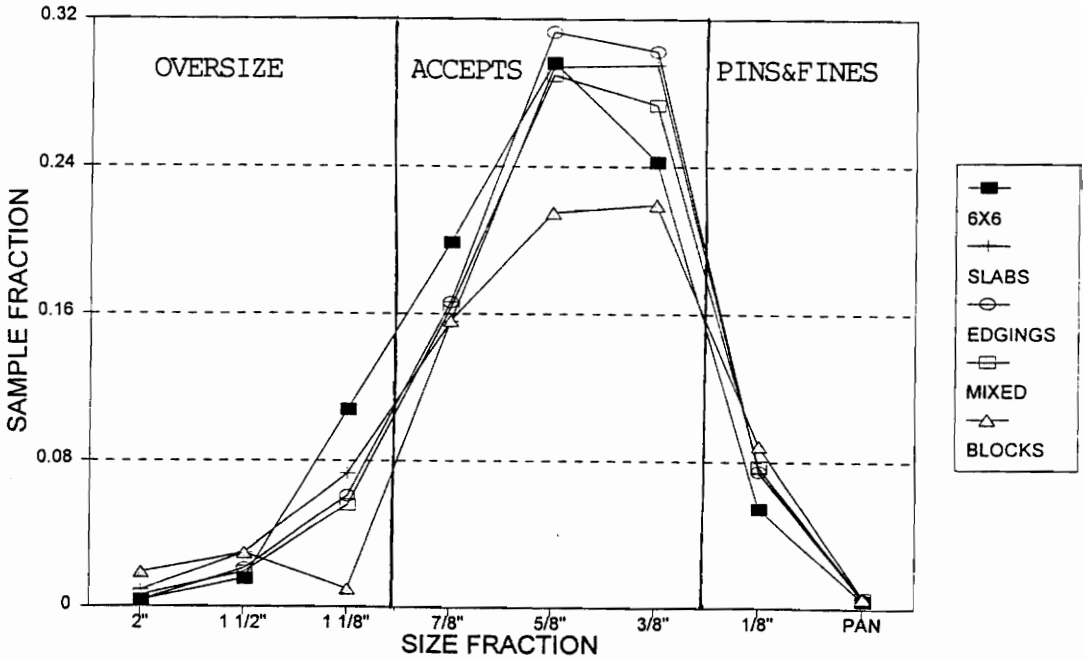

Figure 4.32 - Chip size distribution for the five materials at 100% disk speed.

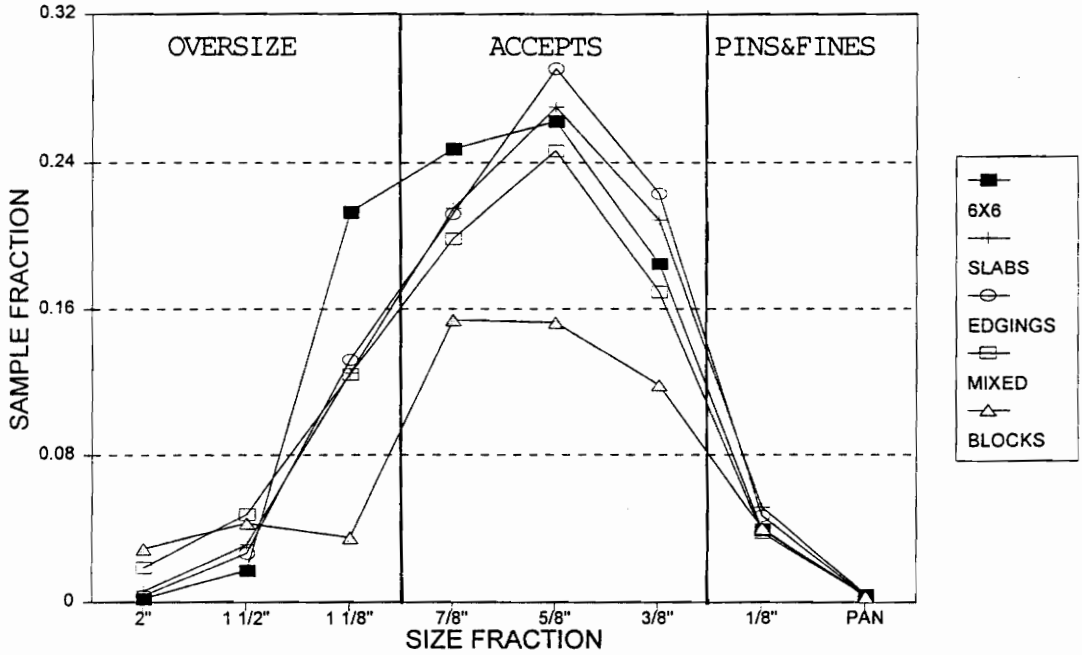

Figure 4.33 - Chip size distribution for the five materials at 70% disk speed.

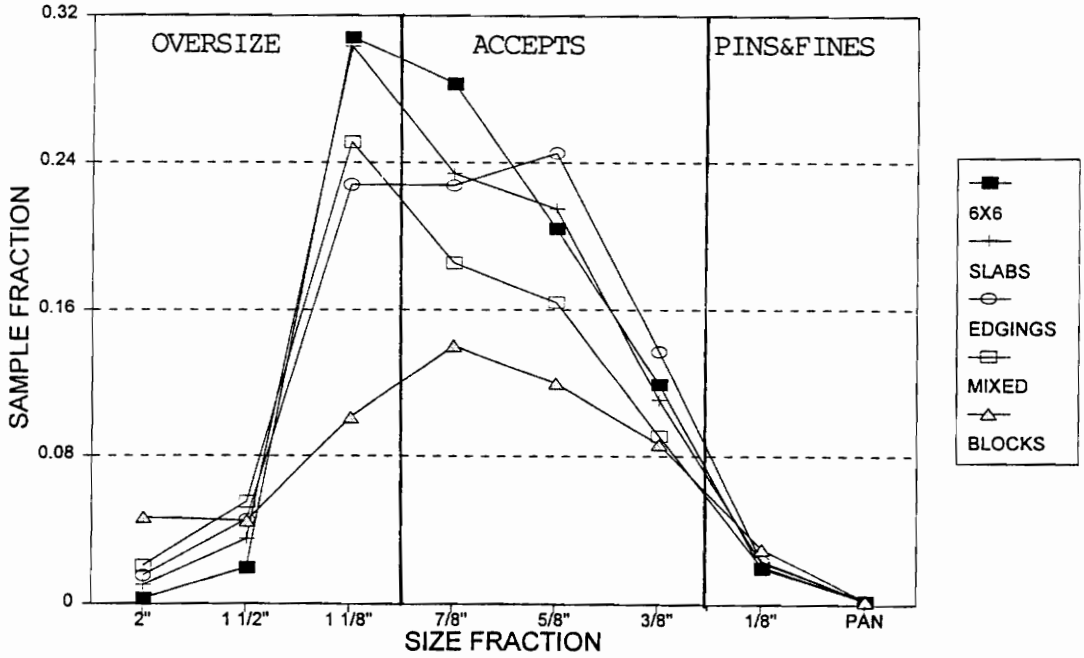

Figure 4.34 - Chip size distribution for the five materials at 50% disk speed.

At 50% disk speed, the shift is even more pronounced. The peak for the cants, slabs, and mixed furnish shifted to the 1-1/8-in. category. The peak for the blocks remained at 7/8-in., but the distribution flattened out considerably (Figure 4.34). The edgings showed a flat distribution across the 1-1/8-in., 7/8-in., and 5/8-in. size classes, with the 5/8-in. category being approximately 1.8% higher than the other two. All but five of the 45 two-tailed, two-sample t-tests performed on the nine size fractions for the five material types rejected the null hypothesis at the 95% significance level or higher. Thirty- two of those tests rejecting the null hypothesis did so at the 99.9% significance level, indicating a significant difference between the sizes of chips produced at 50% disk speed and 100% disk speed.

Overthicks

The production of overthick chips from slabs, edgings, mixed furnish, and trim blocks is inversely proportional to disk speed (Figure 4.35). The differences between the overthicks produced from slabs at 70% and 50% disk speeds were not significant at the 95% significance level, but those produced at 70% disk speed were significantly different from the control at the 90% level. The amount of overthick chips produced from edgings showed a definite

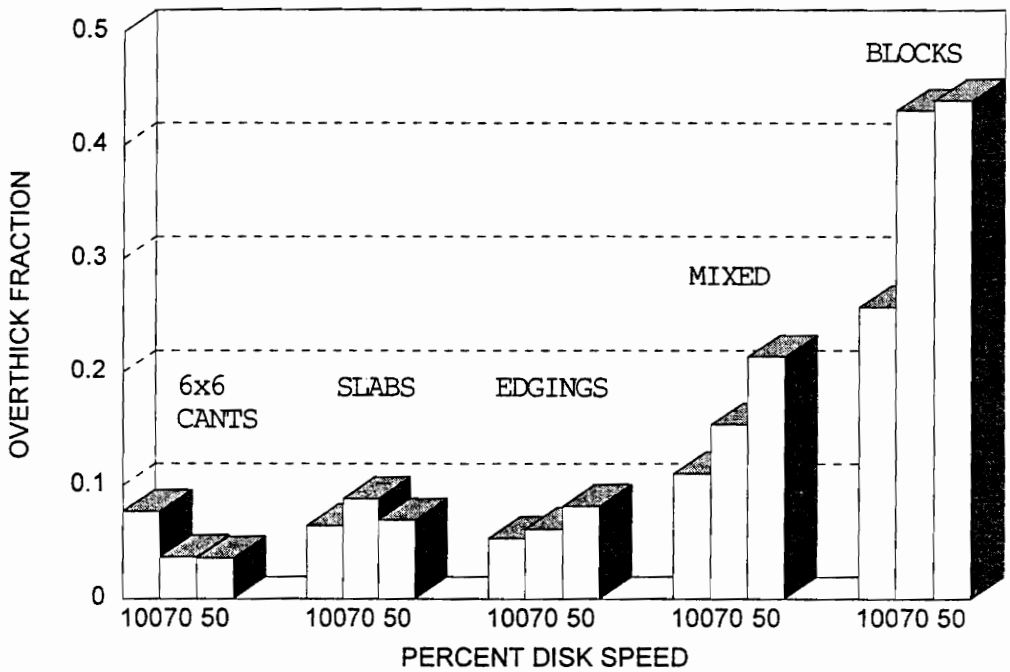

Figure 4.35 - Overthick fraction as a function of disk speed for the five materials.

inverse relationship to disk speed, but only those produced at 50% disk speed were significantly different from the control at the 95% level or higher. The mixed furnish and the trim blocks showed the largest increase in overthicks produced as disk speed decreased. From the 100% speed to 70% speed, the overthick chips produced from the mixed furnish increased by 4.4% (significant at the 90% level) and from the trim blocks by 17.3% (significant at the 99.9% level). When the disk speed decreased to 50%, the overthicks from the mixed furnish increased another 6% (significant at the 99.9% level). The trim blocks showed little change - less than 1% - in the amount of overthick chips produced when the disk speed decreased from 70% to 50%, but when compared to the control, the difference was significant at the 99.9% level. The 6x6 cants showed just the opposite relationship than that exhibited by the other four material types. As disk speed decreased from 100% to 70%, the amount of overthick chips decreased by 4%. The amount of overthicks produced remained virtually unchanged as the disk speed decreased from 70% to 50% (less than 1% difference between the two). The differences in overthicks produced by the two test speeds and the control were significantly lower at the 99% significance level.

Pins and Fines

All five material types produced strong, positive relationships between disk speed and the amount of pins and fines produced (Figure 4.36). As disk speed decreased, the amount of pins and fines decreased. The largest decrease for the 6x6 cants and slabs occurred when the speed decreased from 70% to 50% (2% and 3% respectively). The pins and fines produced from the edgings, mixed furnish, and trim blocks decreased the most between 100% and 70% (3%, 4%, and 5% respectively). A 50% reduction in speed from 707 rpm to 353.5 rpm reduced the pins and fines by two-thirds for all material types. The decrease was linear for all five material types across the range of speeds tested (Figure 4.36). Only two of the ten t-tests performed on the means of the fines from the five material types did not show a significant difference at the 99% significance level or higher. Nine of the ten t-tests performed on the means of the pins from the five material types showed a significant difference at the 99.9% level. The tenth test was significant at the 95% level.

Pulpable Chips

The simultaneous decrease in both overthick chips and pins and fines combined together to increase the total

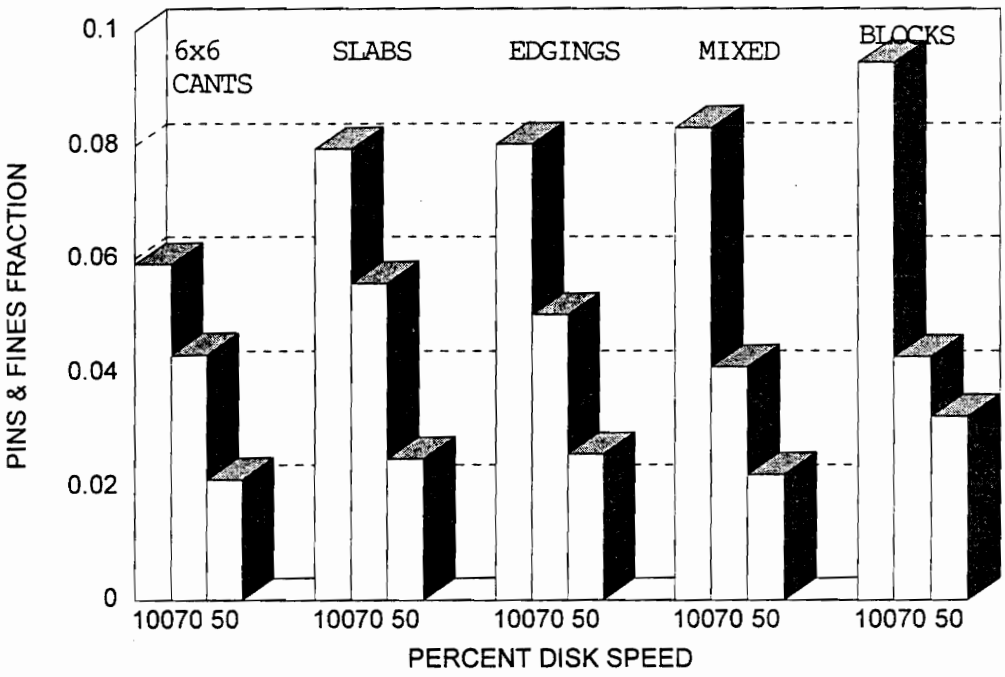

Figure 4.36 - Pins and fines fraction as a function of disk speed for the five materials.

amount of pulpable chips from 6x6 cants as disk speed decreased. The amount of pulpable chips increased by 7.25% when the speed was decreased from 100% to 50% (Figure 4.37). Even though the pulpable chips increased with decreasing disk speed, the amount of accepts decreased by 13% as the disk speed dropped from 100% to 50%. This was mostly due to the sharp increase of 20% in the amount of oversized chips produced (Figure 4.38). The slabs showed a similar chip size distribution. The amount of pulpable chips remained unchanged as the disk speed was decreased from 100% to 70%, but at 50% disk speed, the amount increased by 5% (Figure 4.39). A sharper decrease in pins and fines offset the slight increase in overthicks. Thus the overall effect was to increase the amount of pulpable chips (Figure 4.40). As with the cants, the amount of oversized chips produced from slabs increased sharply by 23.6% as disk speed decreased from 100% to 50%, resulting in a sudden decrease in accepts of 18% (Figures 4.40 and 4.39). The chip size distributions for edgings were almost identical to that of the slabs. Pulpable chips increased by 3% over the range of test speeds, while accepts decreased by 17% over the same range. These changes were influenced by a sharp (20%) increase in oversize chips and the corresponding decrease of 5.5% in pins and fines (Figures 4.41 and 4.42). The amount of pulpable chips from the mixed furnish remained virtually unchanged between 100% disk speed and 70% disk speed, but

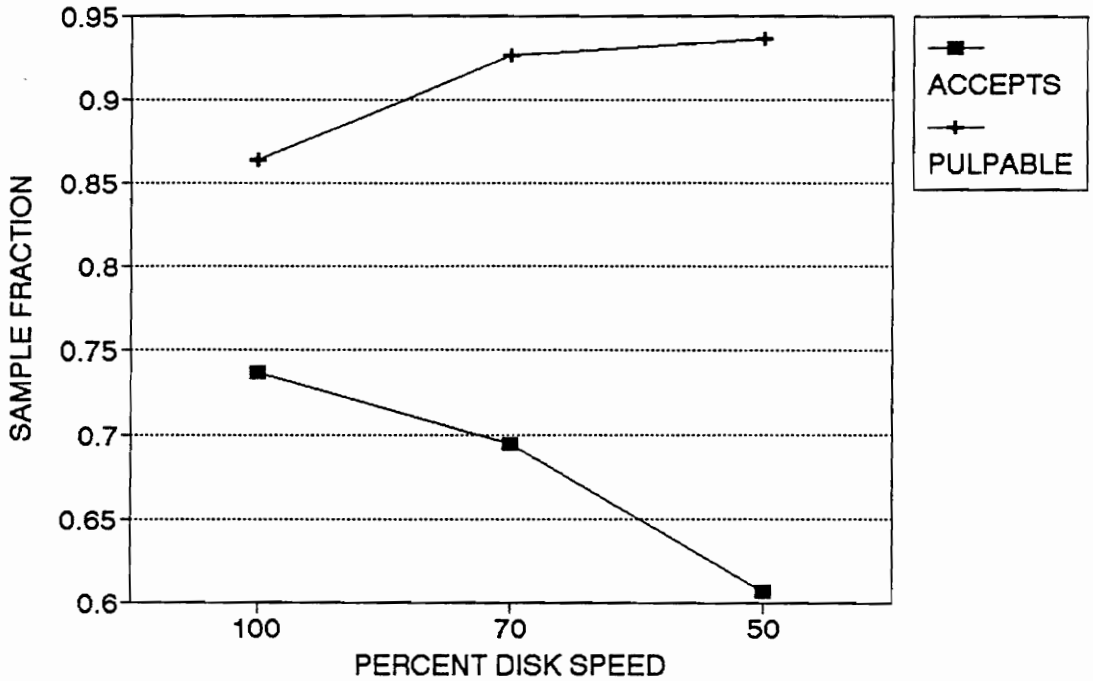

Figure 4.37 - Pulpable and acceptable chips vs. disk speed from cants.

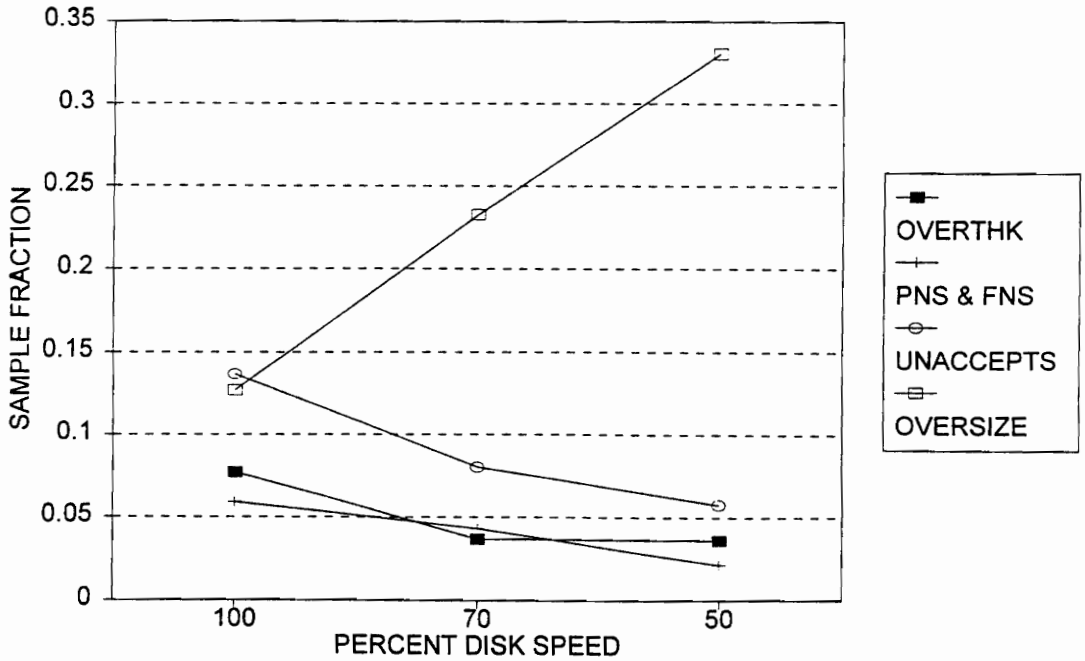

Figure 4.38 - Overthick, oversize, pins and fines, and unacceptable chips vs. disk speed from cants.

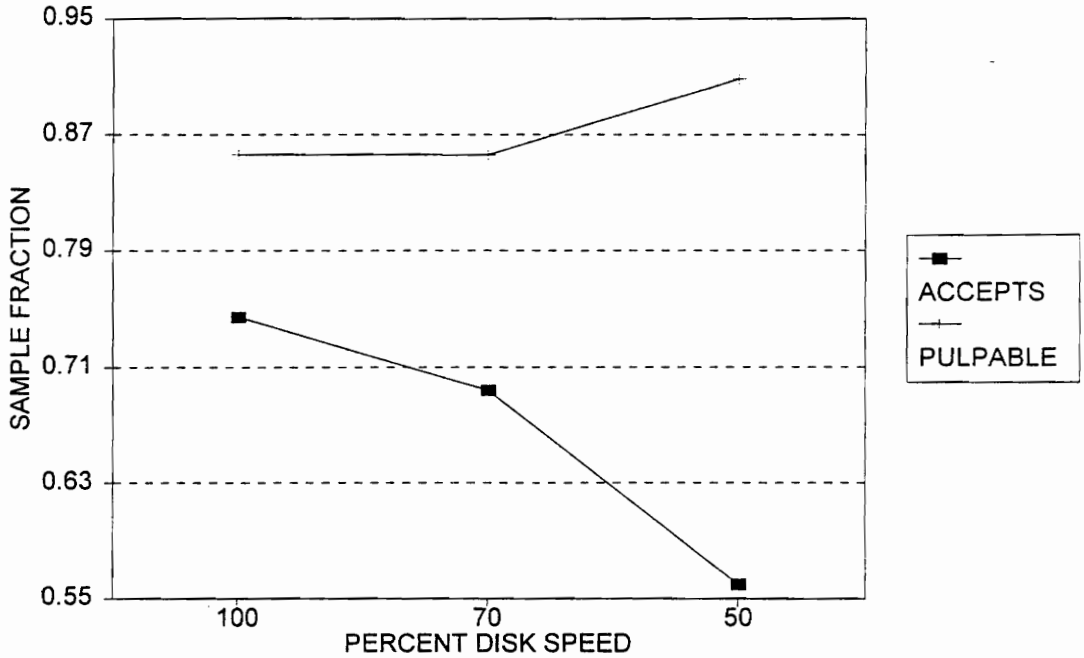

Figure 4.39 - Pulpable and acceptable chips vs. disk speed from slabs.

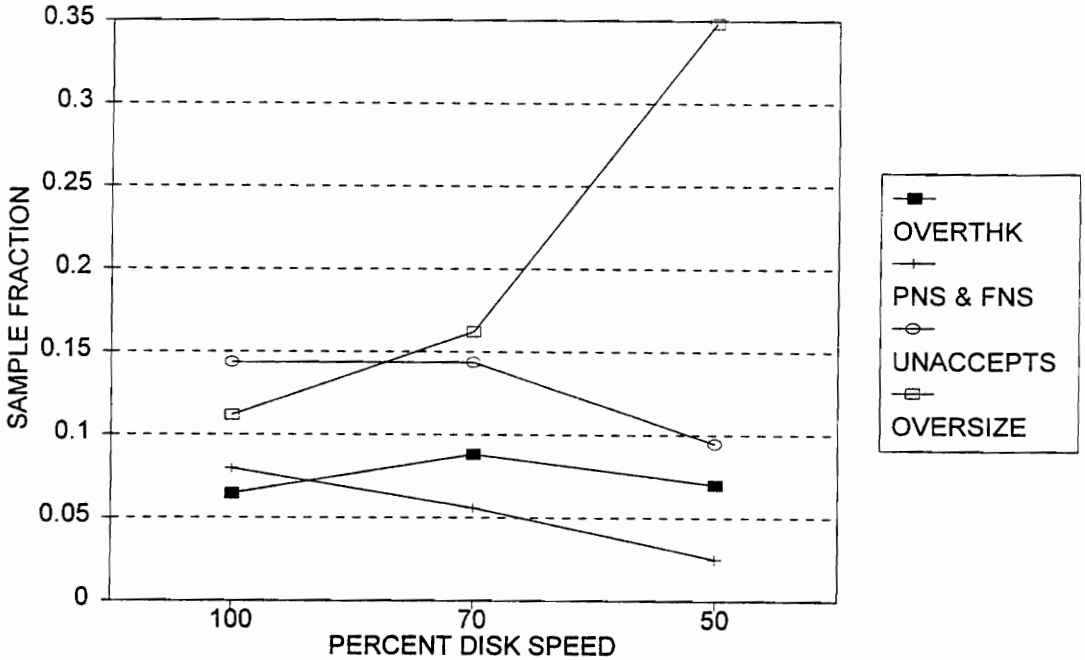

Figure 4.40 - Overthick, oversize, pins and fines, and unacceptable chips vs. disk speed from slabs.

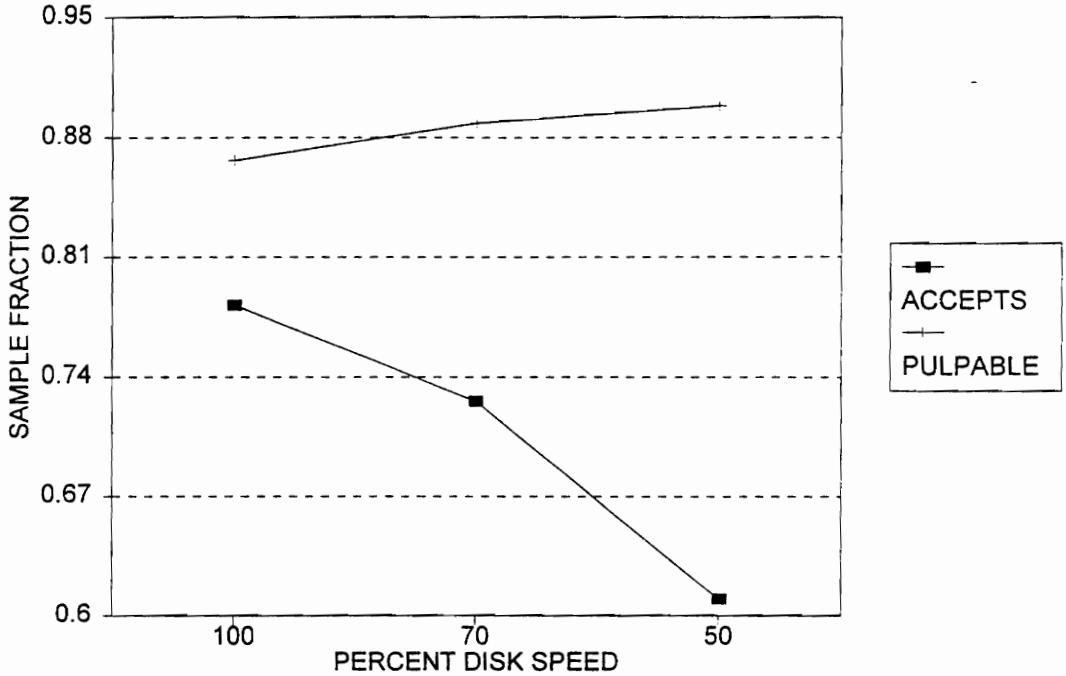

Figure 4.41 - Pulpable and acceptable chips vs. disk speed from edgings

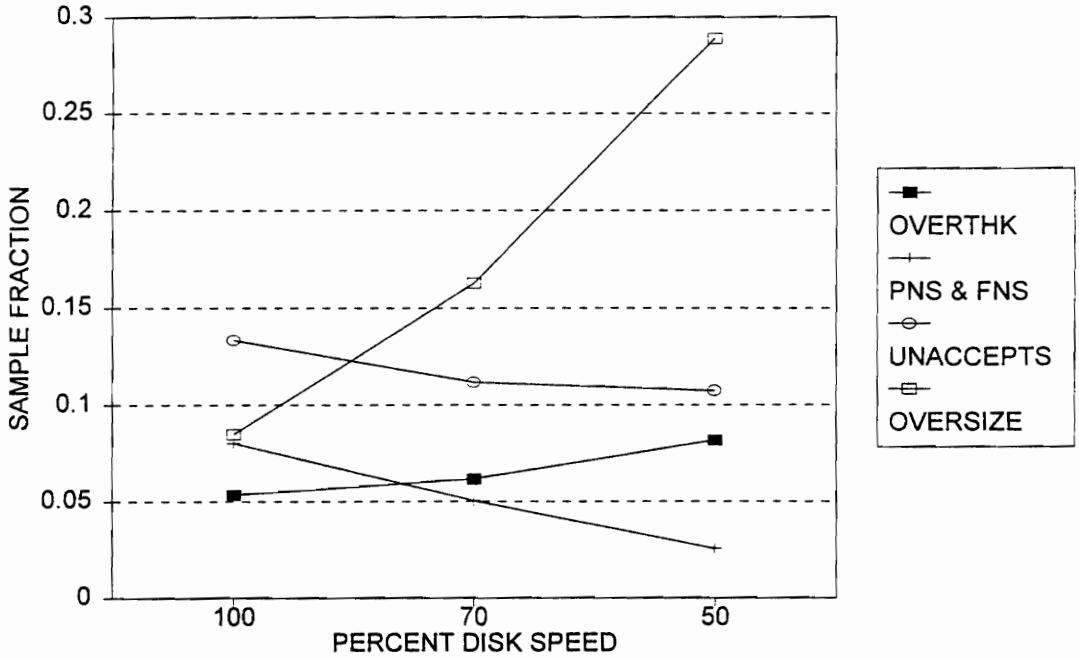

Figure 4.42 - Overthick, oversize, pins and fines, and unacceptable chips vs. disk speed from edgings.

decreased by 4% as the speed decreased to 50% (Figure 4.43). This was largely due to the significant increase in the amount of overthick chips produced as disk speed decreased. This significant increase in overthick chips offset the decrease in pins and fines over the test range of disk speeds (Figure 4.44). The amount of pulpable chips from trim blocks decreased sharply, then remained unchanged as disk speed decreased across the test range (Figure 4.45). As with the mixed furnish, a sharp increase in overthicks at the two test speeds offset any gain realized from the corresponding decrease in pins and fines (Figure 4.46).

Table 4.5 lists the statistical significance between the two test speeds and the control.

EFFECT OF ANVIL CONDITION ON CHIP SIZE DISTRIBUTION

To test the effect of anvil condition on chip size distribution, the new anvil was replaced with one that was extensively worn. To simulate conditions of an anvil becoming worn with no compensating adjustments being made (which is often the case), the knife to anvil distance was not reset when the anvil was changed. This resulted in a larger knife to anvil clearance. The theory is that without a flat, uniform surface for support against which the chipper knives force the wood, the wood tends to shatter instead of chipping cleanly.

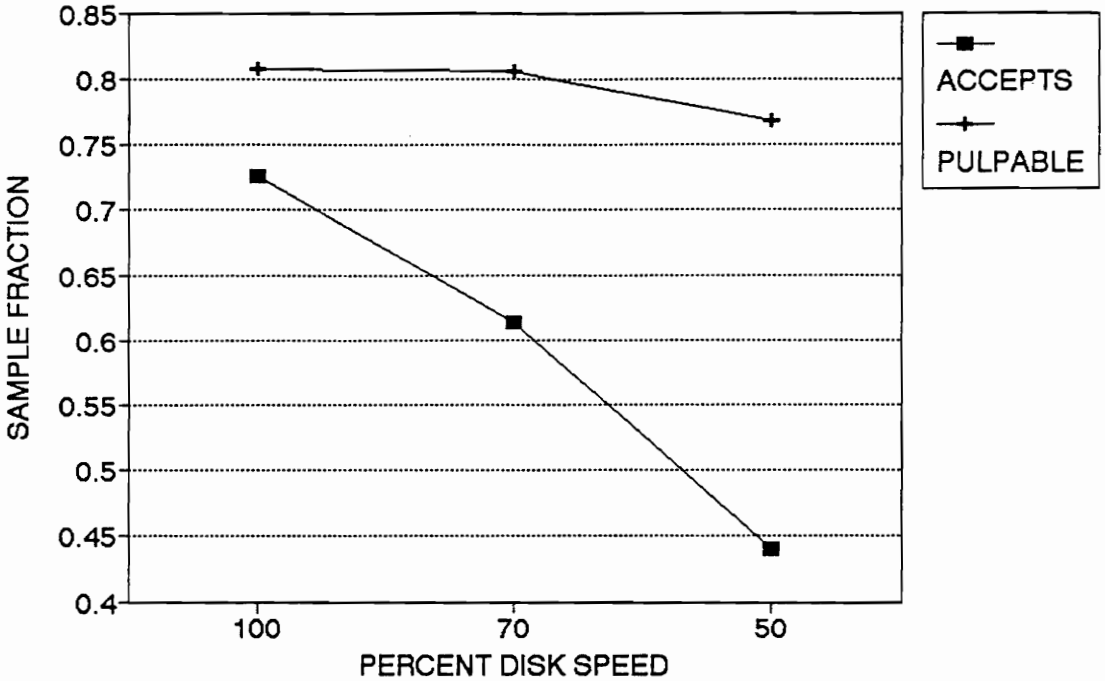

Figure 4.43 - Pulpable and acceptable chips vs. disk speed from mixed furnish.

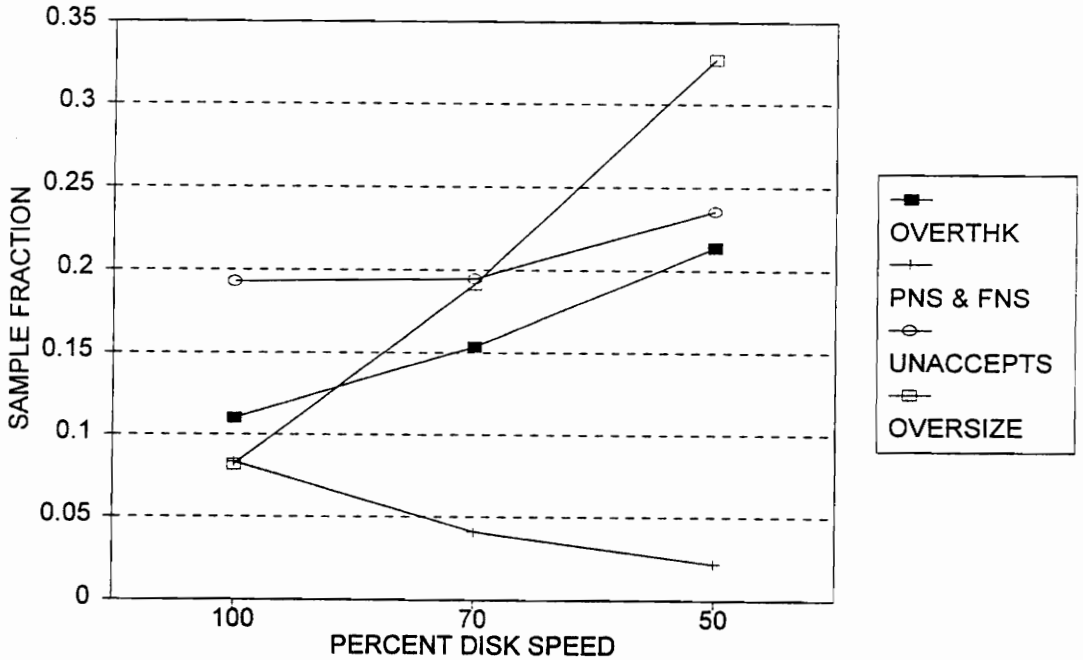

Figure 4.44 - Overthick, oversize, pins and fines, and unacceptable chips vs. disk speed from mixed furnish.

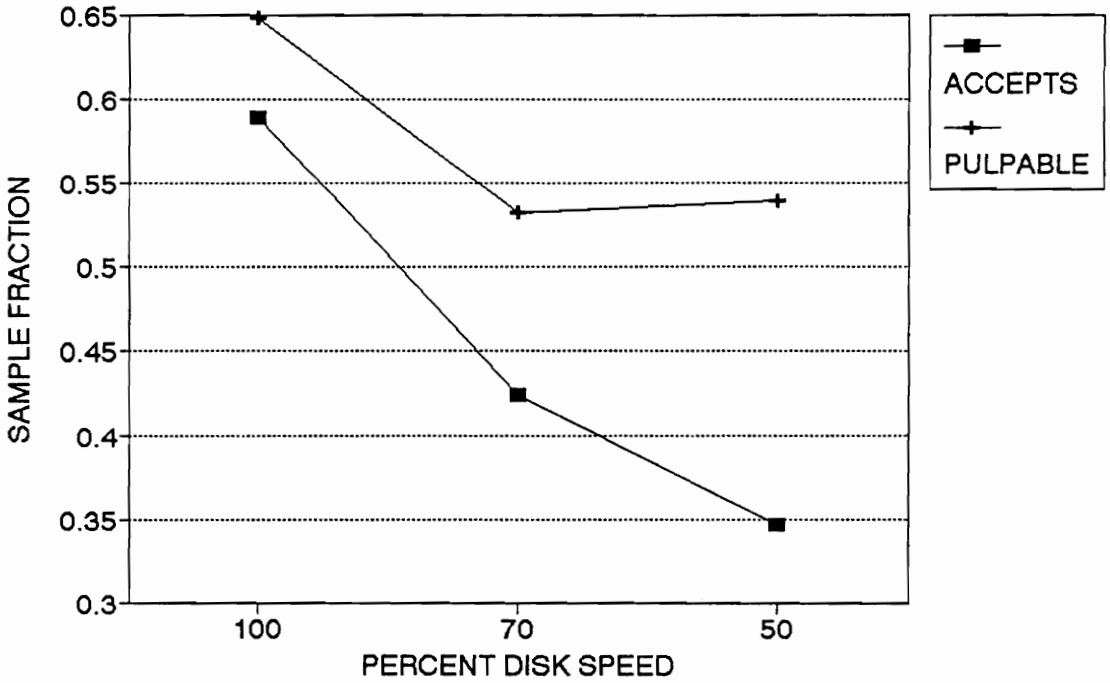

Figure 4.45 - Pulpable and acceptable chips vs. disk speed from trim blocks.

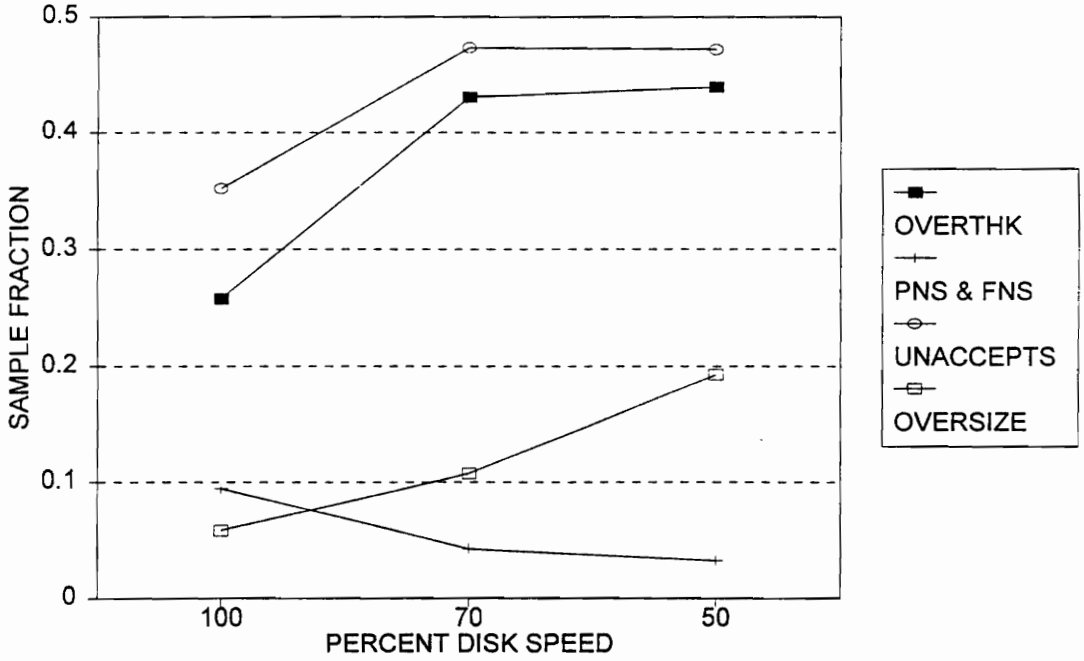

Figure 4.46 - Overthick, oversize, pins and fines, and unacceptable chips vs. disk speed from trim blocks.

Table 4.5 - P-level for two-sample comparison of the two test disk speeds and the control (100% speed).

Trial	Material	8 mm	2"	1-1/2"	1-1/8"	7/8"	5/8"	3/8"	1/8"	PAN
70% SPEED	CANTS	***			****	****	****	****	**	
	SLABS	*			**	****	***	****	****	
	EDGINGS				****	****	***	****	****	****
	MIXED	*	****	****	****	****	****	****	****	****
	BLOCKS	****	**	***	*		****	****	****	****
50% SPEED	CANTS	***			****	****	****	****	****	***
	SLABS				****	****	****	****	****	****
	EDGINGS	**	***	****	****	****	****	****	****	****
	MIXED	****	****	****	****	**	****	****	****	****
	BLOCKS	****	****	***	***	**	****	****	****	****

LEGEND

SYMBOL	P-VALUE	S. L.
*	(10% 0.100)	90%
**	(5% 0.050)	95%
***	(1% 0.010)	99%
****	(.1% 0.001)	99.9%

The control served as the new anvil trial. The chip size distributions for the five material types are shown in Figure 4.47. Figure 4.48 illustrates the chip size distribution for the worn anvil trial. The distribution for the cants changed little. The largest size class (5/8-in.) remained the same, but a large percentage of the total distribution shifted to the 3/8-in. category. The distributions for the slabs and mixed furnish shifted toward the 5/8-in. category. With the new anvil (control), the largest size category was shared between the 5/8-in. and 3/8-in. size classes. After installation of the worn anvil, the percentage of chips in the 3/8-in. class decreased, thus leaving the peak in the 5/8-in. class. The edgings had a shift of the largest chip size category from the 5/8-in. category to the 3/8-in. size class. The distribution for the trim blocks flattened out, with the 5/8-in. and 3/8-in. size classes continuing to share the largest percentage of the distribution. Overall, there was no strong or consistent trend or shift of the chip size distributions for any of the material types when the new anvil was replaced with the worn anvil. Of the 45 two-sample t-tests comparing means of the eight size fractions of the five material types, 18 rejected the null hypothesis of no differences between the means at the 95% significance level or higher. Of those eight, 12 were located within the 5/8-in. size class or smaller. However, since there were conflicting

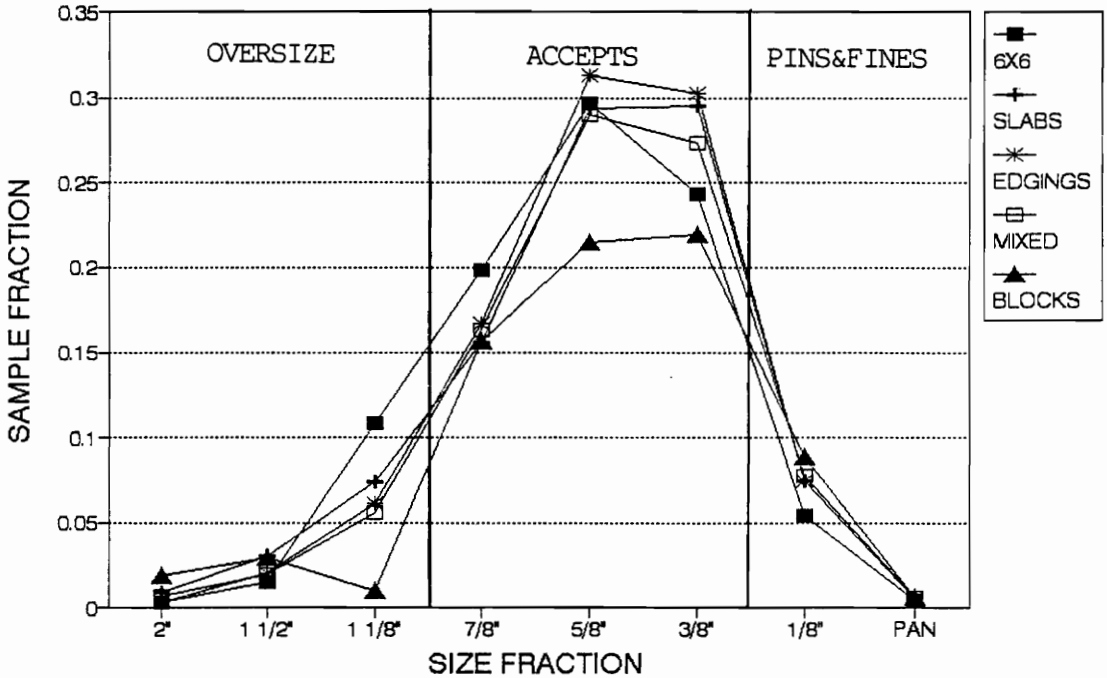

Figure 4.47 - Chip size distribution for the five materials with the new anvil.

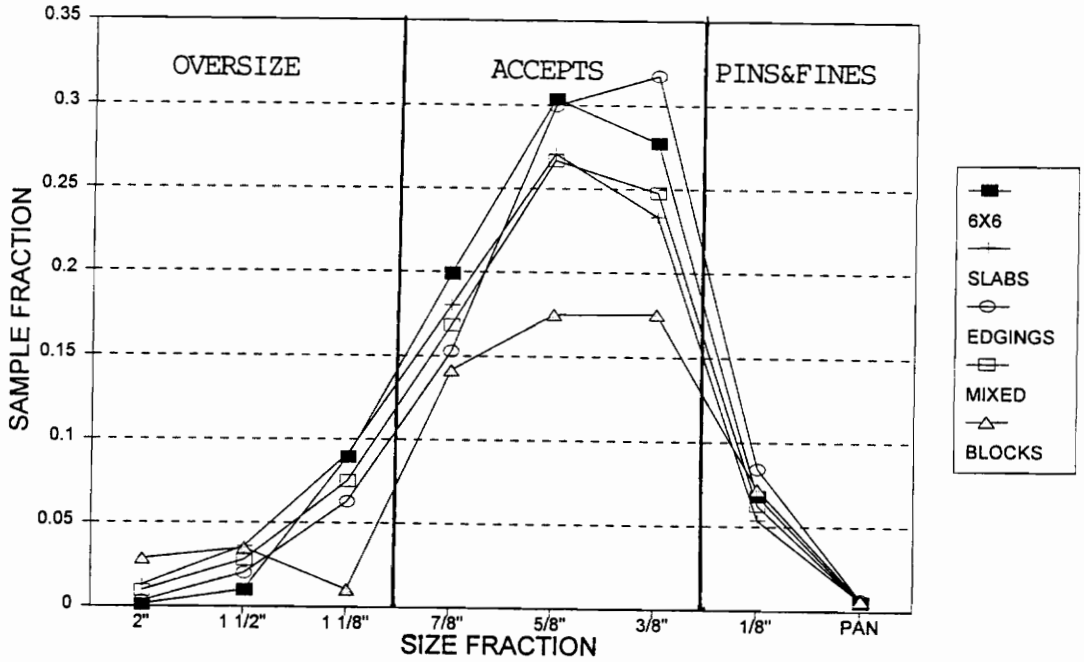

Figure 4.48 - Chip size distribution for the five materials with the worn anvil.

results between material types as to whether or not they were significant increases or decreases, no general conclusions can be drawn from the data.

Overthicks

The 6x6 cants were the only material type to show a decrease in overthick chips due to anvil wear (Figure 4.49). The decrease was significant at the 95% level. The slabs and trim blocks showed significant increases in overthicks at the 99% level or higher. The edgings showed virtually no difference between the two trials. The mixed furnish showed a slight increase in overthicks of 2.8%, but this was not statistically significant.

Pins and Fines

Figure 4.50 illustrates the differences in pins and fines produced as a result of anvil wear. The 6x6 cants and the edgings both showed slight increases in pins and fines when the new anvil was replaced with the worn anvil. The slabs, mixed furnish, and trim blocks all showed decreases in pins and fines production as a result of anvil wear. Of the 10 two-sample t-tests performed on the pins and fines fractions, six rejected the null hypothesis at the 95% significance level.

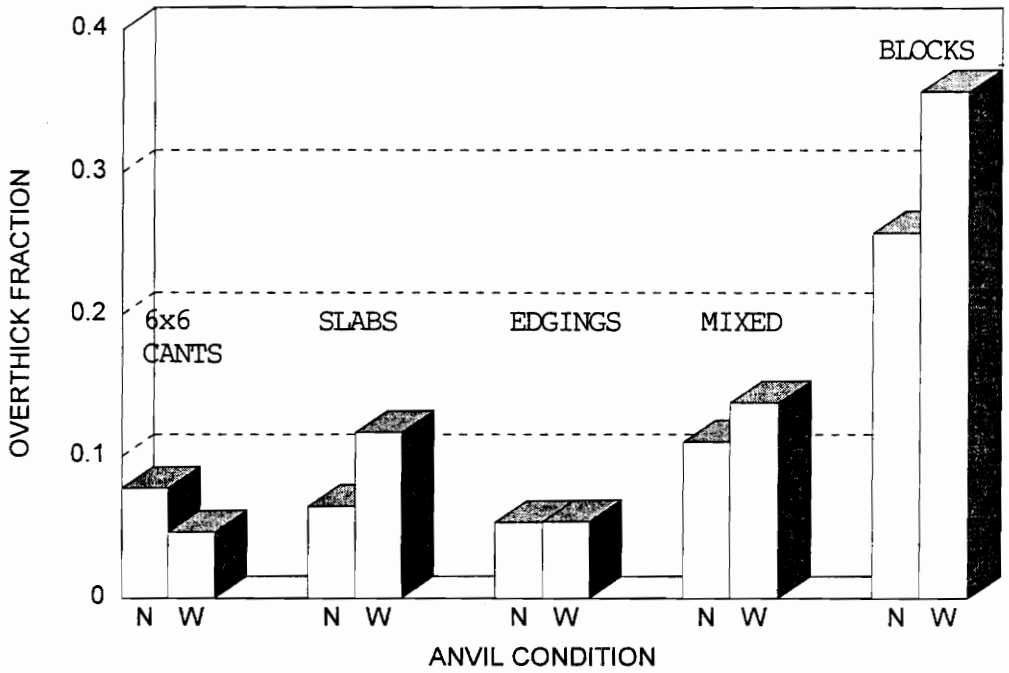

Figure 4.49 - Overthick fraction as a function of anvil condition for the five materials.

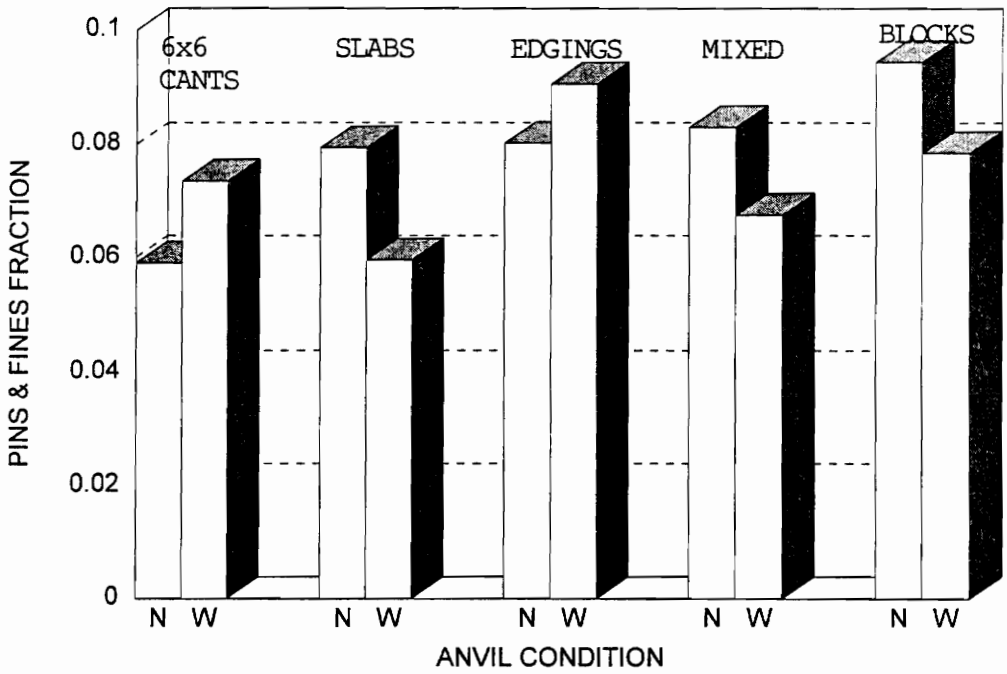

Figure 4.50 - Pins and fines fraction as a function of anvil condition for the five materials.

Pulpable Chips

The amount of pulpable chips increased by 1.6% for the 6x6 cants when the worn anvil was installed (Figure 4.51). A significant decrease in overthick chips in conjunction with a significant decrease in oversize chips shifted more of the chips into the acceptable category (Figure 4.52). The other four material types all exhibited slight decreases in both pulpable and acceptable chips. The pulpable chips produced from slabs decreased by 3% due to a significant increase in overthicks (Figures 4.53 and 4.54). The edgings and mixed furnish both produced approximately 1% fewer pulpable chips after the installation of the worn anvil (Figures 4.55 and 4.57). The distribution of all the chip classifications obtained from edgings remained relatively unchanged between the two trials (Figure 4.56). The mixed furnish showed a slight increase in the overthick chips and a similar increase in the oversize chips produced with the worn anvil (Figure 4.58). The trim blocks exhibited the most sensitivity to anvil condition. The amount of pulpable chips decreased by 8.3% after installation of the worn anvil and the accepts decreased by 9.8% (Figure 4.59). Figure 4.60 illustrates that the major contributing factor of the decrease in pulpable chips was the 9.9% increase in overthicks.

Table 4.6 lists the statistical significance between the

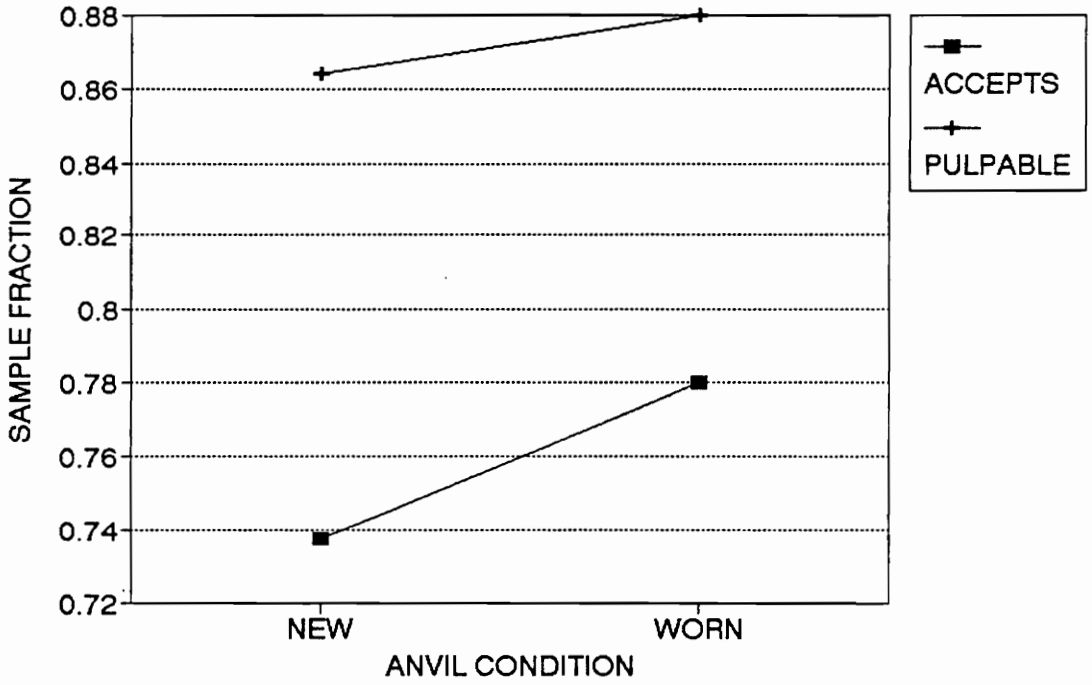

Figure 4.51 - Pulpable and acceptable chips vs. anvil condition from cants.

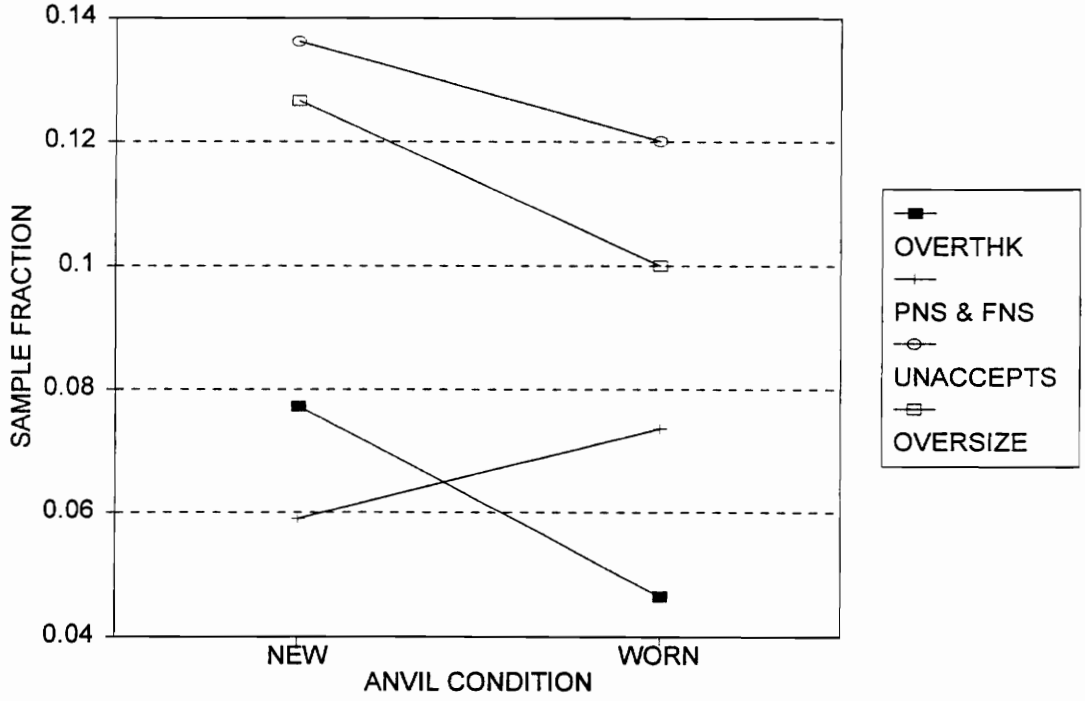

Figure 4.52 - Overthick, oversize, pins and fines, and unacceptable chips vs. anvil condition from cants.

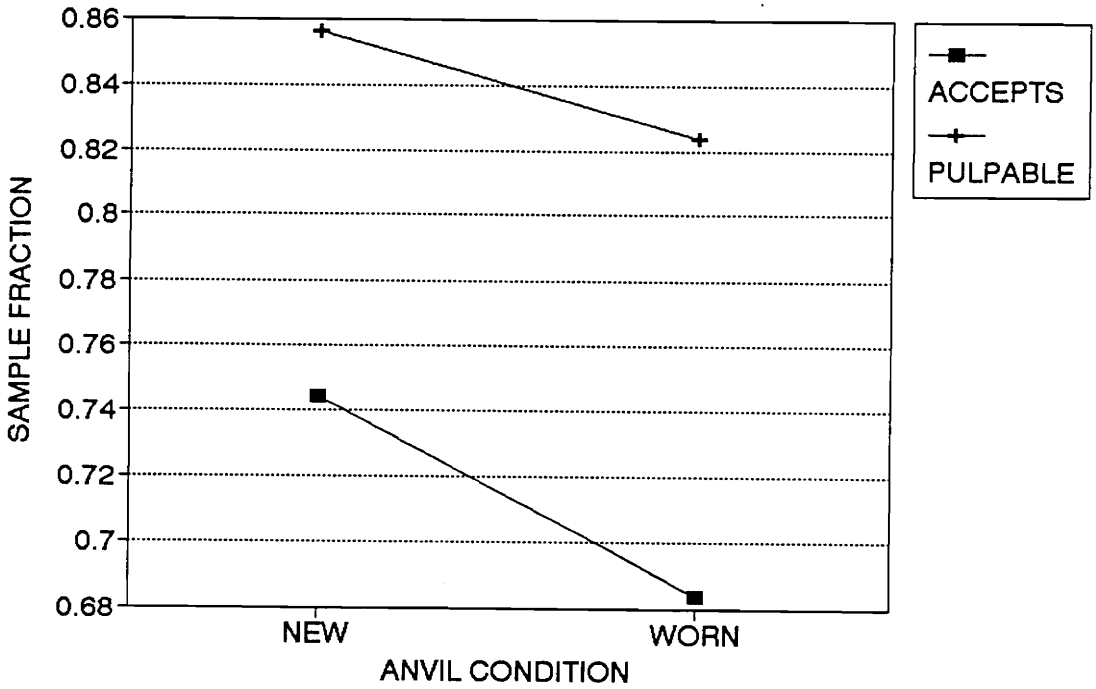

Figure 4.53 - Pulpable and acceptable chips vs. anvil condition from slabs.

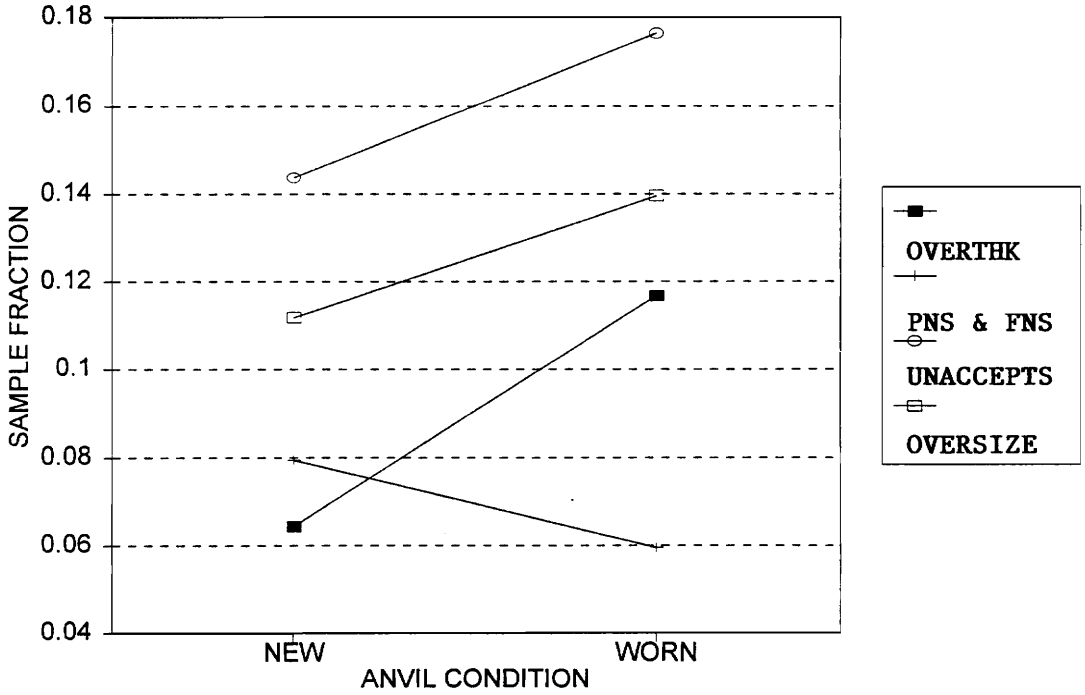

Figure 4.54 - Overthick, oversize, pins and fines, and unacceptable chips vs. anvil condition from slabs.

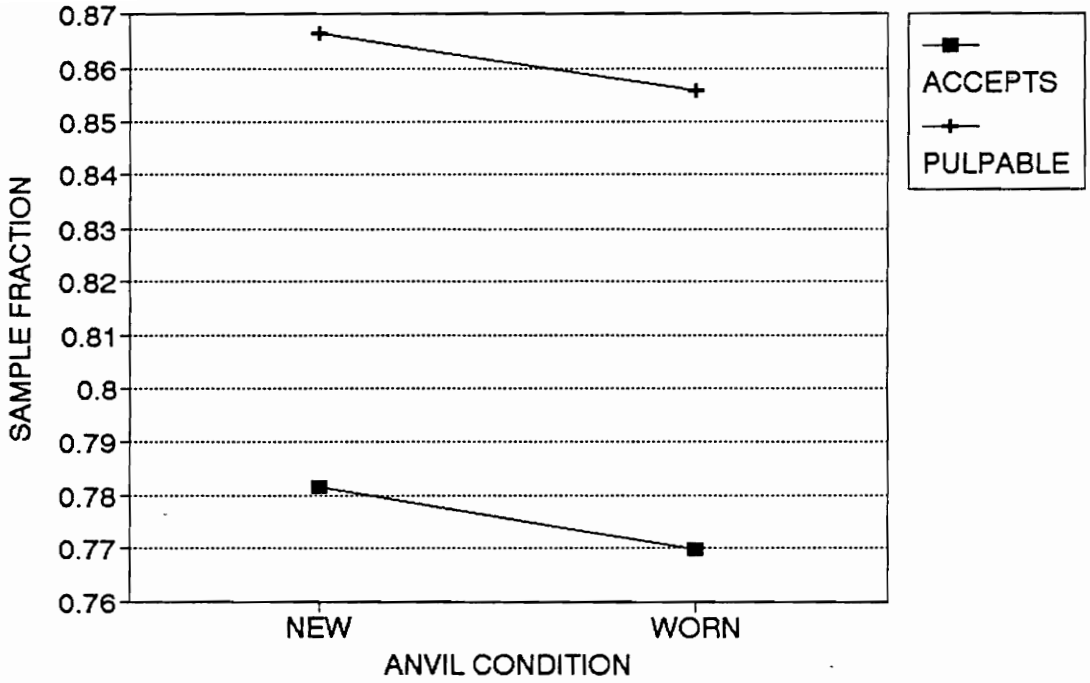

Figure 4.55 - Pulpable and acceptable chips vs. anvil condition from edgings.

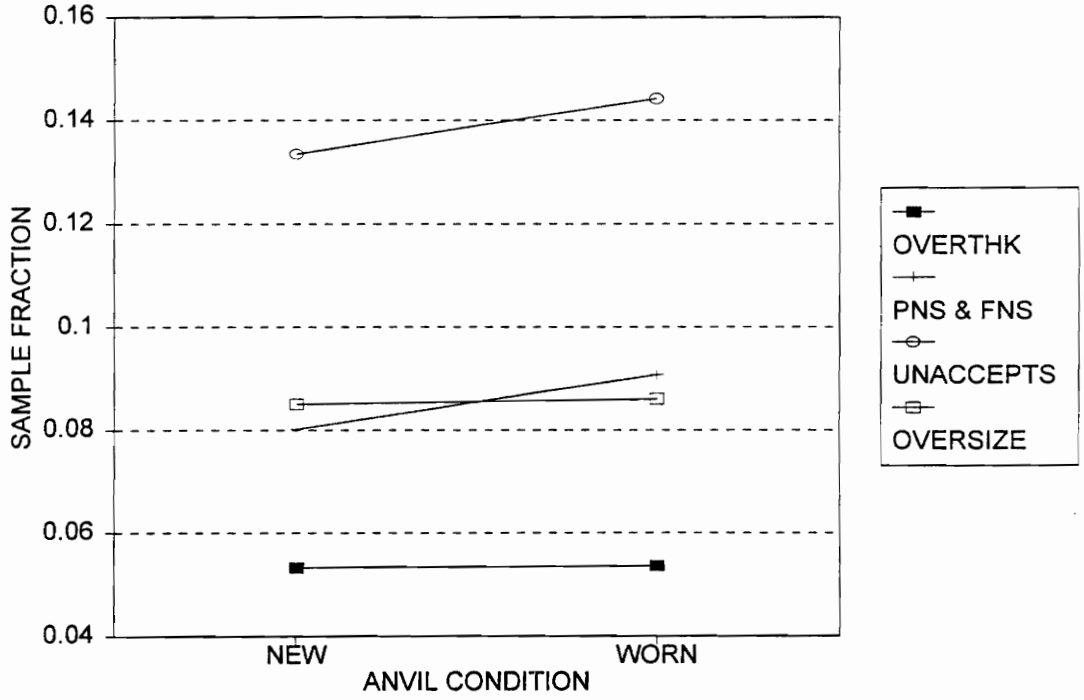

Figure 4.56 - Overthick, oversize, pins and fines, and unacceptable chips vs. anvil condition from edgings.

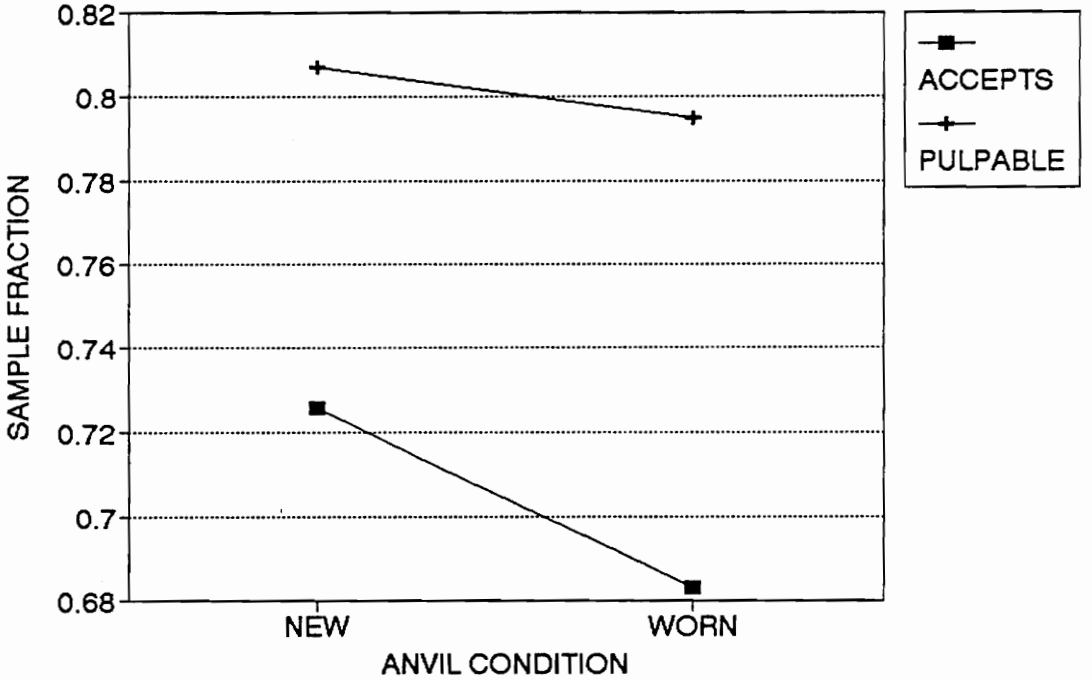

Figure 4.57 - Pulpable and acceptable chips vs. anvil condition from mixed furnish.

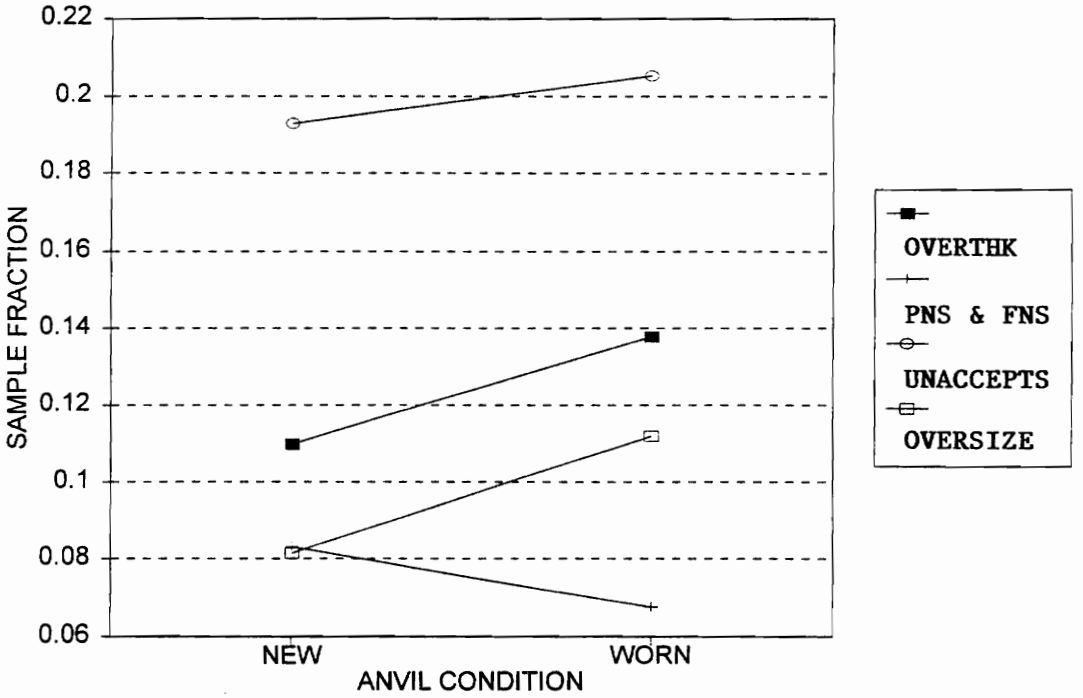

Figure 4.58 - Overthick, oversize, pins and fines, and unacceptable chips vs. anvil condition from mixed furnish.

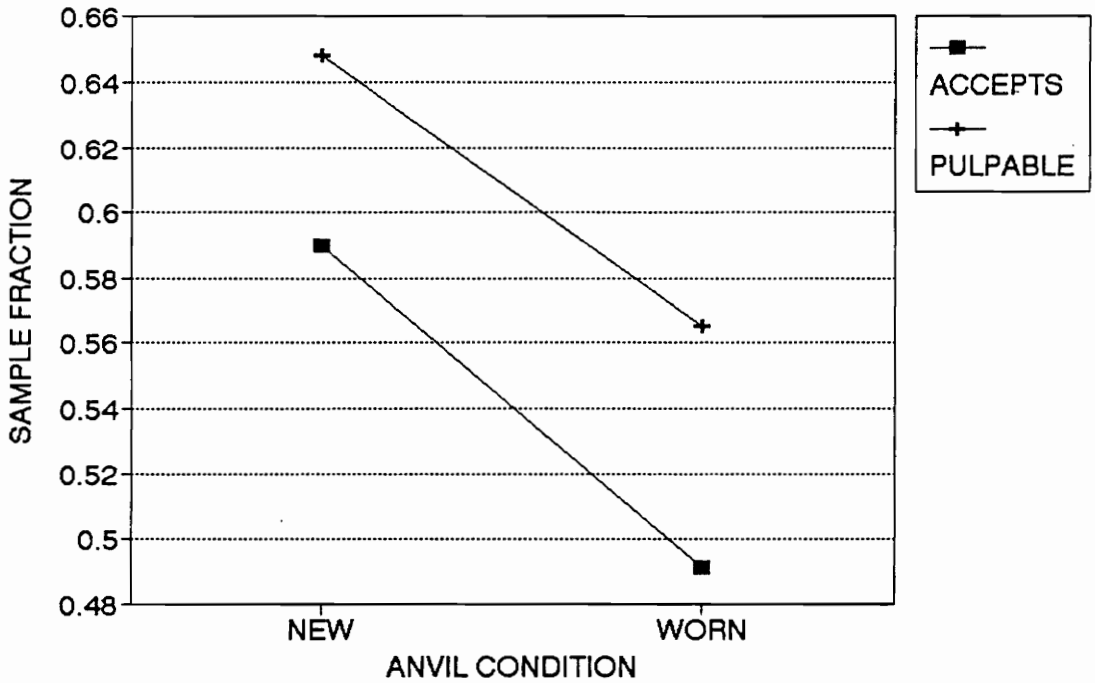

Figure 4.59 - Pulpable and acceptable chips vs. anvil condition from trim blocks.

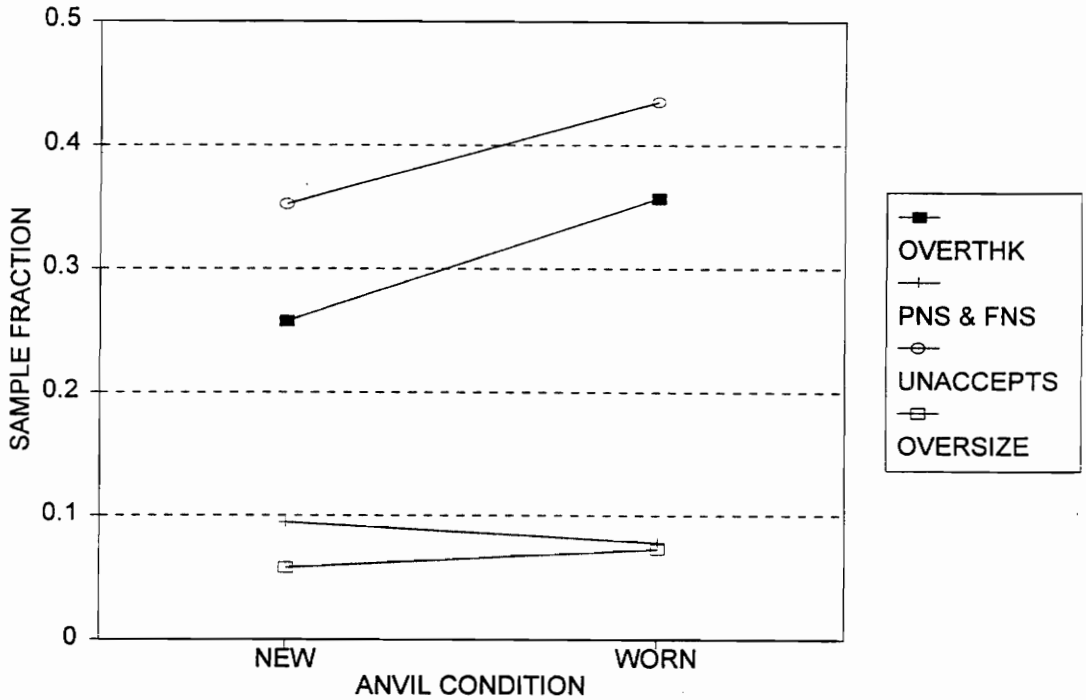

Figure 4.60 - Overthick, oversize, pins and fines, and unacceptable chips vs. anvil condition from trim blocks.

Table 4.6 - P-level for two-sample comparison of the worn anvil and the control (new anvil).

Trial	Material	8 mm	2"	1-1/2"	1-1/8"	7/8"	5/8"	3/8"	1/8"	PAN
WORN	CANTS	**	*	**				**	**	
ANVIL	SLABS	***			**	****	**	****	****	**
	EDGINGS					*	*			**
	MIXED				*		**	*	***	
	BLOCKS	****	*			*	****	***	**	

LEGEND

SYMBOL	P-VALUE		S. L.
*	(10%	0.100)	90%
**	(5%	0.050)	95%
***	(1%	0.010)	99%
****	(.1%	0.001)	99.9%

two anvil conditions.

EFFECT OF MATERIAL TYPE ON CHIP SIZE DISTRIBUTION

The data for the 6x6 cants in each trial was used as the standard of comparison for the other four material types (slabs, edgings, mixed furnish, and trim blocks). Two-tailed, two-sample t-tests were used on the nine chip size fractions for a total of 360 tests. Of the 360 tests, 237 rejected the null hypothesis that the means were equal at the 90% significance level or higher. At the 95% significance level or higher, 215 of the 360 tests rejected the null hypothesis (Table 4.7). Even though significant differences existed across all material types, the trim blocks showed the greatest difference in chips produced from those produced by 6x6 cants. Of the 90 tests performed on the nine chip size classifications for all 10 trials, 75 rejected the null hypothesis at the 95% significance level or higher. Of those, 62 rejected the null hypothesis at the 99.9% significance level. Across all 10 trials, the trim blocks consistently produced more amounts of the 8mm, 2-in., and 1-1/2-in. chips than the cants, with 29 of the 30 tests rejecting the null hypothesis at the 99% level or higher. The trim blocks tended to produce fewer chips in the 1-1/8-in., 7/8-in., 5/8-in., and 3/8-in. size classes than the cants, with 37 of the 40 tests rejecting the null hypothesis

Table 4.7 - P-level for two-sample comparison of the slabs, edgings, mixed furnish, and trim blocks to the cants.

Trial	Material	8 mm	2"	1-1/2"	1-1/8"	7/8"	5/8"	3/8"	1/8"	PAN
FIRST CONTROL	SLABS		***	***	**	****		****	***	
	EDGINGS	*			**	****	**	****	***	
	MIXED				***	****		**	***	
	BLOCKS	****	****	****	****	****	****		****	*
30 DEG. ANGLE	SLABS		**	**		**				**
	EDGINGS									**
	MIXED	****	****	****		**	***			*
	BLOCKS	****	****	****	**	****	****	****		
32 DEG. ANGLE	SLABS	*	*	*						
	EDGINGS			**			**			
	MIXED	*	****	****				**		
	BLOCKS	****	****	****	***		****	**		
33 DEG. ANGLE	SLABS			**						**
	EDGINGS				***	****		**	***	****
	MIXED	****	****	****	**	*	***	***		
	BLOCKS	****	****	****	****	****	****	****	**	***
CHILLED	SLABS	**	**	****	*			***		
	EDGINGS	**	**	***						
	MIXED	****	***	***			****	***		*
	BLOCKS	****	****	***		**	****	****		
FROZEN	SLABS	**	**	***	*	***	****		***	***
	EDGINGS	***		***	****	****	****	**	****	****
	MIXED	****		****	****	****	****	*	**	
	BLOCKS	****		****	****	****	****	****	****	****
70 % SPEED	SLABS	***	*	**	****	****		*	**	
	EDGINGS	*			****	****	****	***		
	MIXED	****	****	****	****	****	*			
	BLOCKS	****	****	****	****	****	****	****		**
50 % SPEED	SLABS	***	**	***		****				
	EDGINGS	***	***	****	**	****	****			
	MIXED	****	****	****		****	***	**		
	BLOCKS	****	****	****	****	****	****	***	**	
WORN ANVIL	SLABS	****	****	****		**	**	***	****	
	EDGINGS		**	****	***	****		**	**	**
	MIXED	****	****	***		***	***	*		
	BLOCKS	****	****	****	****	****	****	****		*
SECOND CONTROL	SLABS	*	*	*						
	EDGINGS	*	**		****	****		**	****	****
	MIXED	****	**	**	***	**	***	**	**	***
	BLOCKS	****	***	***	***	****	****	****	****	****

LEGEND

SYMBOL	P-VALUE	S. L.
*	(10% 0.100)	90%
**	(5% 0.050)	95%
***	(1% 0.010)	99%
****	(.1% 0.001)	99.9%

at the 95% significance level or higher. The trends for the pins and fines production were not as clear. Only 11 of the 20 tests rejected the null hypothesis at the 90% significance level or higher, and only nine out of the 20 tests rejected the null hypothesis at the 95% significance level or higher. Of those nine tests, eight showed significantly higher amounts of pins and fines, and one test showed that the trim blocks produced significantly fewer pins and fines than the cants in that test (70% disk speed).

The results of the comparisons between the cants and mixed furnish tended to mirror that of the trim blocks. Of the 90 tests performed on the mixed furnish data, 54 rejected the null hypothesis at the 95% significance level or higher. Of those, 43 rejected the null hypothesis at the 99% significance level or higher. The mixed furnish produced larger amounts of chips in the 8mm, 2-in., and 1-1/2-in. size classes, and fewer chips in the 1-1/8-in., 7/8-in.,5/8-in., and 3/8-in. size classes. As with the trim blocks, the results for the pins and fines were not conclusive. Only six of the 20 tests rejected the null hypothesis at the 90% significance level or higher. Five out of the six tests rejecting the null hypothesis showed significant increases in pins and fines. One test (fines production in the chilled trial) showed a significant decrease in fines produced.

The slabs and edgings showed similar trends as those of

the mixed furnish and trim blocks, but the differences were not as pronounced. Fifty of the 90 tests comparing the edgings to the cants rejected the null hypothesis at the 90% significance level or higher, with 47 rejecting the null hypothesis at the 95% significance level or higher. The edgings tended to produce larger amounts of 8mm, 2-in., and 1-1/2-in. chips than the cants. Unlike the trim blocks and mixed furnish, the trend for the 1-1/8-in. through the 3/8-in. size classes was not as consistent. The edgings produced fewer amounts of chips in the 1-1/8-in. and 7/8-in. size classes than the cants, but the results from the 5/8-in. and 3/8-in. size classes were varied. Of the 20 tests performed on those two size classes, 11 were significant at the 90% level or higher. Of those 11, 10 showed increases in the amounts of chips produced, unlike the results from the trim blocks and mixed furnish. One test (5/8-in. size class, frozen trial) showed a significant decrease over those produced by cants. Of the 20 tests performed on the pins and fines, only 10 rejected the null hypothesis. All 10 tests rejecting the null showed significant increases in pins and fines produced.

According to the data, slabs produced chips most similar to those produced by cants when compared to the other material types. This can be expected since slabs are more like cants in size, shape, and the way they feed into the chipper than the other material types. Forty-nine of the 90

tests rejected the null hypothesis at the 90% level or higher, while only 39 tests rejected the null hypothesis at the 95% level or higher. More 8mm, 2-in., and 1-1/2-in. chips were produced from the slabs than from the cants in all 10 trials. The slabs tended to produce fewer 1-1/8-in., 7/8-in., 5/8-in., and 3/8-in. chips than the cants. However, only 16 of the 40 tests performed on those size classes showed a significant decrease in the amount of chips produced. Although only seven of the 20 tests performed on pins and fines rejected the null hypothesis of no differences between the means, the trend appears to be that slabs produce more pins and fines than cants.

Although there are some slight variations in the data, the general trend seems to be that slabs, edgings, mixed furnish, and trim blocks produce more overthick and oversize chips, fewer amounts of acceptable chips, and more pins and fines than 6x6 cants. The slabs produced chip distributions most similar to those produced by cants, with edgings close behind in similarities. The mixed furnish showed greater differences between it and cants than those shown by slabs and edgings. The trim blocks produced vastly different chip size distributions than those produced by 6x6 cants.

CHAPTER 5. SUMMARY AND CONCLUSIONS

Sawmill residue chips compose up to 50% of the fiber utilized by pulp mills. In the past, the quality of sawmill chips has been poor when compared to those chips produced in the wood rooms of pulp mills. Even small increases in useable fiber reaching the digesters have a significant economic impact on both the pulp mill and the sawmill supplying the chips. Most of the research on chipper design characteristics, more specifically the effects of knife angle, disk speed, anvil condition, and seasonal variations (temperature) on chip quality has been done on pulp mill wood room or whole-tree chippers. These chippers deal with a much different furnish than the residue chippers in sawmills. One purpose of this study was to determine if the principles governing roundwood chipping apply to sawmill residue chipping, and to make recommendations to improve chip quality.

Ten trials examining the effects of knife angle, temperature, disk speed, and anvil condition were conducted at Chesapeake Corporation's West Point, VA hardwood sawmill in mid-July 1990. The mill is equipped with a 60-in. (152-cm) diameter, six-knife, vertical disk chipper manufactured by Fulghum Industries. The chipper was restored to factory-fresh condition by the manufacturer immediately before the trials. The tests were conducted using Loblolly pine (Pinus

taeda L.) samples. Each trial consisted of three replications each of the four material types (6x6 cants, slabs, edgings, trim blocks) and a mix to approximate the normal flow to a sawmill chipper. For the knife angle trials, four brand new sets of knives were used, each sharpened to one of the four angles tested. The wood for the temperature trials was chilled in a refrigerated van. The disk speeds for the speed trials were obtained by using the drift-down method developed by Mark D. Robinson (1989). The new anvil was replaced by an extensively worn anvil to determine the effect of anvil wear on chip quality. Beginning and ending control trials were used to monitor any significant changes that may have occurred in the physical characteristics of the chipper during the course of the trials. They also served as a standard of comparison for the knife angle, temperature, speed, and anvil wear trials. The chips were classified by using a Williams Classifier.

KNIFE ANGLE

No strong, consistent relationships could be found between knife angle and the production of overthick chips. Of the 15 two-tailed, two-sample t-tests performed on the data, only five rejected the null hypothesis of no differences between the means. Three of those significant differences were in the 33 degree trial, but the results varied from one

material type to another as to whether or not the significant differences were increases or decreases. The 6x6 cants showed a significant decrease in overthicks at a 33 degree knife angle, while the mixed furnish and trim blocks showed significant increases in overthicks.

There appears to be a trend of increasing pins and fines production with increasing knife angle. Only the mixed furnish showed a decrease in pins and fines produced as knife angle increased. However, the trend of increasing pins and fines with increasing knife angle is not strong enough to warrant any firm and definite conclusions. Of the 30 two-sample t-tests performed on the pins and fines fractions, only seven rejected the null hypothesis of no difference at the 95% level or above.

The range of angles tested (from 30 deg. to 33 deg.) was quite narrow. The variability inherent to the residue material may have overwhelmed subtle differences and trends. A greater range of angles and larger experimental units will be required to support or refute the presence of trends. Based on the inconclusive results of this study, it is not possible to recommend one knife angle over another.

TEMPERATURE

Reducing wood temperature prior to chipping produced conflicting results in the percentages of overthick chips.

The 6x6 cants, slabs, and edgings showed overall decreases in overthicks, and the mixed furnish and trim blocks exhibited definite increases in overthicks. Because of the variation in the data, the results from this study are inconclusive. Further investigation is needed to formulate any concrete conclusions on the effects of temperature on overthick chip production.

Chilling and freezing wood prior to chipping resulted in significant increases of pins and fines in all five material types. One hypothesis to explain the increase in pins and fines during the winter months is that the physiological changes in the wood during the dormant seasons have an effect on the way the wood chips. All of the material used in this study was from trees harvested during the active growth stage in June and July. The significant increase in pins and fines shown here indicates that temperature has a greater effect on chipping than physiological changes in the wood due to dormancy.

A second hypothesis was that the increase in pins and fines was due to the presence of frozen water crystals in the wood. This study indicates that freezing is not a necessary condition. The increase in pins and fines produced when the temperature changed from ambient (95 deg. F) to chilled (36 deg. F) accounts for roughly half of the total increase in pins and fines as the wood is cooled from ambient to frozen conditions.

From the results of this study, it would appear that a sawmill could reduce the amount of pins and fines produced in the colder months by heating the wood before it is chipped. Each mill would have to evaluate its own situation to determine if the added cost of installing and operating a heater of some sort - a heated flume for example - would be justified by the economic gain obtained by the decrease in pins and fines. The cost of heating wood in the northern mills may be so great that the added cost would overwhelm any benefit gained by the reduction in pins and fines.

DISK SPEED

Reducing the disk speed of the chipper significantly decreased the percentage of pins and fines produced. The effect of disk speed on the production of overthick chips varied in both direction and magnitude. The 6x6 cants exhibited a 4% decrease in overthicks as the speed decreased from 100% (707 rpm) to 70% (495 rpm). The amount of overthicks produced remained virtually unchanged as the disk speed decreased from 70% to 50% (354 rpm). The slabs had an increase in overthick chips at 70% disk speed, but then the amount decreased by 1.8% at 50% disk speed, resulting in an overall increase in overthick chips of .5%. The other three material types had significant increases in overthicks as disk speed decreased. The decrease in overthicks from

edgings was not as pronounced as the mixed furnish and trim blocks. The mixed furnish and trim blocks showed the greatest change in overthicks of all the material types. The variability in both direction and magnitude of the changes indicates that additional research in warranted. The large increase in overthick chips from blocks is possibly due to the ability of the blocks to turn in the knife pocket as the disk revolves more slowly. The entire length of a trim block can sometimes pass sideways through the infeed spout. Thus, the block contacts the disk face with its long axis parallel to the knives. This sometimes results in a large splinter being torn from the entire length of the block instead of a clean chip being cut from the wood.

All five of the material types produced strong, positive relationships between disk speed and the amount of pins and fines produced. The 6x6 cants and slabs exhibited their largest decreases in pins and fines between the 70% and 50% disk speeds. The other three material types had their largest decreases between the 100% and 70% speeds.

The amount of pulpable chips increased with decreasing disk speed for the cants, slabs, and edgings. The pulpable chips from the mixed furnish and trim blocks showed a decrease over the range of speeds tested, although the decrease in the mixed furnish was small. If a mill is equipped with some method of rechipping or slicing the overthicks, more pulpable chips could possibly be produced by decreasing the

disk speed to reduce pins and fines and rechipping or slicing the overthicks to recover as much pulpable material as possible.

No attempt was made to determine the effect that the decreased speed would have on chipper throughput or on power requirements. Each sawmill would have to evaluate its own residue chipping utilization before any changes in disk speed could be recommended. Some of the aspects of the chipping operation that would need to be evaluated are feed rate of the chipper at lower disk speeds, power draw on the chipper motor, volume of material handled, and the effect that the loss of stored energy due to lower disk speed would have on the chipper motor.

WORN ANVIL

The 6x6 cants were the only material type to show a decrease in overthick chips due to anvil wear. The slabs, mixed furnish, and trim blocks showed increases in overthicks, and the edgings showed virtually no change. The cants and edgings showed slight increases in pins and fines and the slabs, mixed furnish, and trim blocks produced fewer pins and fines with the worn anvil than with the new anvil.

The 6x6 cants showed an increase in pulpable chips, most likely due to the decrease in overthick chips. The rest of the material types all produced slightly fewer pulpable

chips with the worn anvil.

The variations found in the data across the five material types provide few insights for improving chip quality. It appears that anvil wear does not have as pronounced an effect on sawmill residues as it has on roundwood chipping. However, it is still recommended that the anvil be maintained in good working condition as with the rest of the chipper so that the highest possible number of pulpable chips are being produced.

MATERIAL TYPES

Significant differences existed across all material types. Chipping cants, slabs, and edgings resulted in overthick chip percentages ranging from 3% to 10% across all treatments. The blocks produced overthick chip percentages ranging between 25% and 45% of the total. In almost all of the statistical tests performed on the overthicks, the trim blocks were significantly different from the 6x6 cants at the 99% level. The percentages of pins and fines tended to be more uniform across all material types, with the values from the trim blocks only slightly larger than those from the cants, slabs, and edgings. These results indicate that most of the problems in chip quality inherent to sawmill residue chips seem to come from the chipping of trim blocks. Wallace (1993) examined ways to improve the quality of chips

obtained specifically from trim blocks. One important finding was that the quality of the chip distribution is closely related to the length of the trim block. The longer the trim block, the higher the quality of the chip distribution. The relationship between chip quality and trim block length is a result of the orientation of the piece as it reaches the chipper. Trim blocks that are short enough to rotate within the conveyor system will reach the chipper at random orientations. This spinning of the blocks within the infeed spout is the greatest cause of the high percentage of overthicks. The knife splits off pieces along the grain, producing a shingle or shake that has poor pulping characteristics and is difficult to upgrade into a quality chip. Installing a shorts trap in the chipper infeed to separate material less than one foot long for processing either in a specialized chipper or routing directly to fuel would seem a reasonable solution. Egolf (1991) examined several methods of minimizing the spinning and movement of short pieces within the chipper infeed. The different methods examined involved either aligning and positioning pieces before they reached the disk, or restraining them with various hold-down devices.

This study demonstrated that the recommendations for the operation of a roundwood chipper cannot be translated directly to sawmill residue chippers. The areas that were

found to have the greatest promise of improving the quality of sawmill residue chips are

1) disk speed
2) better throat design
3) possibly varying disk speed with fluctuating temperatures to counteract the increase in pins and fines due to colder temperatures.

Some recommendations made from this study were picked up on and investigated further. Edelman (1992) conducted a study which tested a wider range of disk speeds. In addition to his work on trim blocks, Wallace (1993) investigated the effects of a wide range of temperatures on pins and fines production, while Egolf (1991) examined several methods of improving the way in which materials feed into the chipper. This research done on disk speeds has been accepted and put into practice by the sawmill industry. Mills are reducing the speeds of their chippers with positve results. It is hoped that the pioneering efforts and results of this study will encourage even further investigation into the improvement of sawmill residue chips.

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