4-1991

Increasing the Hardwood Content on the Furnish by Separate Refining

David K. Finn
Western Michigan University

INCREASING THE HARDWOOD CONTENT OF THE FURNISH BY SEPARATE REFINING

Submitted as partial fulfillment of the
Bachelors of Science and Engineering Degree
Paper Science and Engineering

Author: David K. Finn

Advisor: Dr. Richard Hartman

April 26, 1991

W E S T E R N   M I C H I G A N   U N I V E R S I T Y

TABLE OF CONTENTS

INTRODUCTION....1

BACKGROUND....1

FIBER MORPHOLOGY....1

REFINING EFFECTS ON FIBER PROPERTIES....2

INTERNAL FIBRILLATION....3

EXTERNAL FIBRILLATION....4

FIBER RUPTURE....4

HW/SW REACTION....5

SEPARATE/ADMIXTURE....6

EXPERIMENTAL PROGRAM....8

OBJECTIVE....9

EXPERIMENTAL APPROACH....9

RESULTS....12

BURSTING STRENGTH....13

TENSILE STRENGTH....14

TEARING STRENGTH....15

SCATTERING COEFFICIENT....16

DISCUSSION....17

CONCLUSION....20

REFERENCES....22

INTRODUCTION

It is an old papermaker's adage that paper is made in the beater. This means that the performance and the physical properties of the paper are determined by the type and the extent of the mechanical action to which the fibers are subjected before they are joined to form paper. The terms used to describe the function of refining; free beaten, wet beaten, et al are all traditionally vague, by reason of the complicated structure of the fibers and the even more complicated changes these fibers undergo during the refining process.

BACKGROUND

Softwood was the raw material used when the chemical pulping process was originally developed. It was not until the late 50's and early 60's that the pulping industry starting using hardwood on a large scale as the raw material. Since then, the amount of hardwood used has increased continuously and is expected to continue to increase due to the large amounts of hardwoods available and to the high cost of softwood pulps.

FIBER MORPHOLOGY

Because the morphology of softwood and hardwood fibers are quite different, they may be expected to behave differently upon refining. As stated by Levlin (3), the Finnish Pulp and Paper Institute has conducted numerous experiments regarding fiber reaction to refining. There appears to be certain systematic differences in the refining behavior of softwood and of hardwood pulps.

Before discussing the refining behavior of the different pulps, it is worthwhile to review general structural differences of softwood and hardwood pulp. As stated by Levlin (3,6) and Giertz (1), hardwood fibers are much shorter and narrower than softwood fibers. Generally, hardwood fibers have a higher relative cell wall thickness than softwood fibers. This means that hardwoods are stiffer and have a greater resistance to collapse. hardwood pulps contain a large amount of thin-walled vessels. Within softwoods, there exists a distinct difference between springwood and summerwood fibers. The difference is much smaller in hardwoods. Hardwood fibers are short, and therefore, have a much smaller rotational volume the softwood fibers. Thus, hardwoods have a lower flocculation tendency. The number of hardwood fibers per unit is much higher than that of softwood fibers.

In summary, refining hardwood fibers involves a much larger number of smaller, stiffer, less collapsible, and less flocculating fibers than refining softwood fibers.

REFINING EFFECTS ON FIBER PROPERTIES

Most agree that the main purpose of refining is to generate inter-fiber bonding activity of the pulp fibers so the paper formed will have sufficient strength properties. The increased inter-fiber bonding is achieved through structural changes in the cell wall of the pulp fibers. The influence of the refining on the fiber structure, as described by Giertz (1), is divided into three major categories: internal fibrillation, external fibrillation, and fiber rupture.

INTERNAL FIBRILLATION

Due to the compression- relaxation-compression of the fibers by the refiner bars, bonds are broken within the fiber wall resulting in fiber swelling, fiber flexibility, and fiber collapse (1).

As the bonds that restrict the swelling of the fiber are broken, the fiber takes on water and hydration occurs. The bonds that restrict swelling are generally hydrogen bonds in the hemicellulose regions or within the microfibrils (4).

Emerton (2) suggests the bonds are broken between the concentric fibrillar layers of the secondary wall so the loosened layers can slip against one another. The swelling of the inter-fibrillar hemicellulose may be a contributing factor to this loosening and lubricating mechanism. The ability of the separate layers to slip past each other makes the fiber more flexible.

The fiber collapses when dried. The hydrogen bonds that are broken as the fiber swells cause the fiber to lose its rigidity and become straight. Upon drying, the fiber collapses and becomes ribbon-like.

EXTERNAL FIBRILLATION

The remainder of the primary wall, if any, is removed by the action of the refiner bars. The outer layer of the fiber is fibrillated, the individual fibrils are loosened and raised from the cell wall. In this first stage of fibrillation it is most likely the outer layer of the S1 wall that fibrillates (1). At this time fines and crill are formed. Fines is defined as any material that will pass through a 200-mesh screen. Crill are fibrils, or thread-like elements that have been removed from the walls of the fiber (2). As the intensity of the refining and the number of impacts are increased, the degree of external fibrillation increases; the S2 wall may begin fibrillation.

External fibrillation causes an increase in the relative surface that is available for bonding. The increased surface area exposes available hydroxyl groups which, in turn, allows for more bonds to form. An increase in the number of bonds will produce a strong sheet.

FIBER RUPTURE

In the case of severe mechanical action, fibers may be crushed and shortened. As the fibers are subjected to extremes in refining loads, the forces that exists at the leading edge of the refining bar literally crush the fibers. At the same time, fibrils are formed, but they now come largely from the S2 wall. A close relationship between fiber shortening and crill formation may also exist. The shortened fibers have fibril ends that stick out of the fiber end. The fibrils may be pulled out of the fiber upon further refining.

HARDWOOD/SOFTWOOD REACTION

Controlling fiber characteristics (1,2,4) are the fiber morphology, the distribution of the chemical constituents, and the physical condition of the fiber. The first two factors depend on the fiber source and on the pulping process used to separate the fibers. It is the third item, the physical condition of the fiber, that is primarily determined by the mechanical treatment the stock receives during preparation for papermaking.

The refining of the fibrous raw material is a critical operation of the papermaking process. It often determines how well the technical requirements of the product are met. Subsequent processes, such as forming and drying, are influenced highly by the conditions used in refining.

Experiments conducted at the Finnish Pulp and Paper Research Institute (3,4) drew these conclusions. The tensile strength for hardwood pulps increased more quickly at a low intensity refining load. Softwood pulps develop tensile strength more fully at a higher refining intensity. While individual cellulosic fibers generally have high tensile strength, the strength of the paper is largely dependent on the bonds between fibers. Refining generally optimizes the bonding potential of the fiber. Because softwood fibers are much larger than hardwood fibers, it follows that they would require a higher degree of refining. Tear strength values are developed reverse of the tensile response. Tear values for softwoods reached a maximum after only a small amount of refining, whereas the tearing strength of hardwoods increased much more slowly.

When considering the development of strength of the two different pulps, the hardwoods develop more fully at a lower intensity while softwoods develop better at a higher refining intensity. In terms of other papermaking properties, hardwoods and softwoods react similarly to refining.

The results of the above experiments indicate that generally the optimum refining conditions for hardwoods and softwoods are quite different. In the case of hardwood pulps, strength development is of high importance. Typically, these properties develop in the most economical way at a rather high refining intensity. In the case of hardwoods, a lower refining intensity is needed.

Because hardwoods develop strength better at a low refining intensity and softwoods need a higher intensity to fully develop strength properties, the pulps need to be refined separately to fully reap the benefits offered from both.

SEPARATE/ADMIXTURE REFINING

Frequently, paper is made from a mixture of hardwood and softwood fibers. The question raised is 'Should the hardwoods and the softwoods be refined separately or after mixing?'

Because the optimum refining conditions for hardwoods and softwoods have been shown to be quite different (3,4), the logical answer is to refine the components separately. By refining the components separately, the refining action may be tailored for both hardwoods and softwoods. A low refining intensity could be used to develop tensile strength in the hardwood furnish, while not adversely affecting scattering coefficient. A high refining intensity could be used on the softwood. This would fully develop the great strength potential of the fibers by increasing the relative bonding area available. Separate refining would also give the process, as a whole, a greater flexibility range and, thus, a larger scope for obtaining certain end properties.

Separate refining of the pulps means a higher investment cost and a more complex refining system. The benefits provided by separate refining must be large enough to justify the added investment costs.

The cost of a ton of softwood pulp may be as high as $900, according to Schuster (5). Hardwood pulp averages $250 less per ton. Because of this price difference, there exists an economical reason for maximizing the hardwood content of the furnish. Depending upon the end properties required of the product and the runnability of the papermachine, the hardwood content of the product may be maximized by separate refining.

Another important aspect of the refining of fiber suspensions is energy use. Refining does mean in fact the application of energy to change the physical characteristics of a fiber suspension. As stated earlier in the text, careful optimization of the refining process may allow for the increase in hardwood content of the furnish. Also stated, hardwoods are better developed under a gentle refining technique (3). A low intensity refining method consumes less energy than a high intensity refining treatment which may result in a reduction in overall energy consumption.

A 400 tpd papermill using 50% softwood and 50% hardwood would realize a 1.75 million dollar savings by increasing the hardwood usage to 60%. This savings would more than compensate for the added capital investment needed for separate refining.

The possible energy savings, together with the lower price of hardwood pulp gives the idea of separate refining credibility.

As observed by Wahren (4), softwood fibers being wider and longer than hardwood fibers, the softwood fibers tend to protect the latter from receiving as harsh a treatment in the refiner. This actually means the hardwood fibers are refined at a lower intensity, and the softwood fibers are refined at a higher intensity than that applied to the entire furnish as a whole. Subsequent experiments have proven this to be of minor practical importance (1,3).

EXPERIMENTAL PROGRAM

Although there have been experiments conducted on the different refining behaviors of hardwoods and softwoods, there remains more to be learned. The fiber morphology of both, the way each reacts to refining, and the best refining method to use to achieve the best end results have all been studied. What has not been studied is: To what extent can hardwood fibers replace softwood fiber? This point has yet to be quantified. By increasing the hardwood content of the papermaking furnish, several benefits may be achieved: the lower cost of the hardwood furnish, possible energy savings, and the full benefit of each fibers inherent properties.

Before a full scale papermaking operation begins to increase the level of hardwood in the furnish, these questions must be answered: Will changes effect machine runnability? Will the product meet customer strength specifications?, and Will the benefits outweigh the added expense? These questions can be addressed through systematic lab and pilot machine work.

OBJECTIVE

For this thesis, an examination of the degree to which hardwood fibers may be substituted for softwood fibers in the furnish, without lowering sheet strength, is proposed. In mill operation, hardwoods and softwoods are normally slurried together and then refined. For this thesis the hardwood and softwood fibers will be refined separately and at different intensities. The hypothesis for this thesis is there must be an increase in the hardwood content of the furnish by a minimum of 10 percent while maintaining sheet strength.

EXPERIMENTAL APPROACH

To remove as much variation as possible, one distinct hardwood and one distinct softwood was chosen. The hardwood was a kraft, Northern birch; the softwood chosen was a kraft, Southern pine. These pulps were chosen because they are widely used throughout the industry.

The refining equipment chosen for this experiment was the Valley beater. This was chosen because of the close correlation with production double disc refiners (7).

The first step was to set up a control to compare the experimental results to. A control was established by refining the samples as a combined mixture. The hardwood/softwood ratios used to set the control were 20%/80%, 30%/70%, and 40%/60%. These ratios were chosen because they are widely used throughout the industry. These mixtures were slushed via a Morden slush maker and refined in the Valley beater to a Canadian standard freeness of 400 milliliters. This stock was used to make handsheets in the British sheet mold. The handsheets were conditioned and tested for burst, tensile, tear, and scattering coefficient. All were done in accordance to TAPPI standards. The resulting values were used to judge the degree of success of the experiment.

The hardwood and softwood pulps were then refined separately. The softwood pulp was refined from an initial CSF of 700 ml down to a CSF of 400 ml. The hardwood pulp was refined from a CSF of 560 ml to a CSF of 400 ml.

The two separate components were combined with the following hardwood/softwood ratios 30%/70%, 40%/60%, and 50%/50%. Handsheets were made, conditioned, and tested for the previously mentioned values.

The values obtained from these tests were compared to the control values obtained from combining the hardwood and softwood prior to refining.

RESULTS

Please refer to the following graphs which compare the controls to the experiments.

For each distinct pulp sample, both pre-mixed and post-mixed, a total of twenty British handsheets were made. After the sheets were conditioned, five sheets were chosen from the twenty. These five handsheets were chosen on basis of formation, basis weight, and caliper. In so doing, the effects of the weight of the sheet and the thickness of the sheet were minimized. The variation for the complete evaluation was limited to +/- three percent (3%).

Because the variation was kept at a very low level, the testing results were not adjusted for basis weight or caliper. It was felt that a straight scale reading was sufficient to show the trends of the experiment. In normal operations where the basis weight and caliper of the samples are varied, the scale values need to be compensated.

In this evaluation, great pains were made to eliminate the variation of these two components. In doing, the adjustment for weight and caliper could be avoided and efforts concentrated on the search for general trends.

FIG. 1 BURSTING STRENGTH

combined vs. separate refining

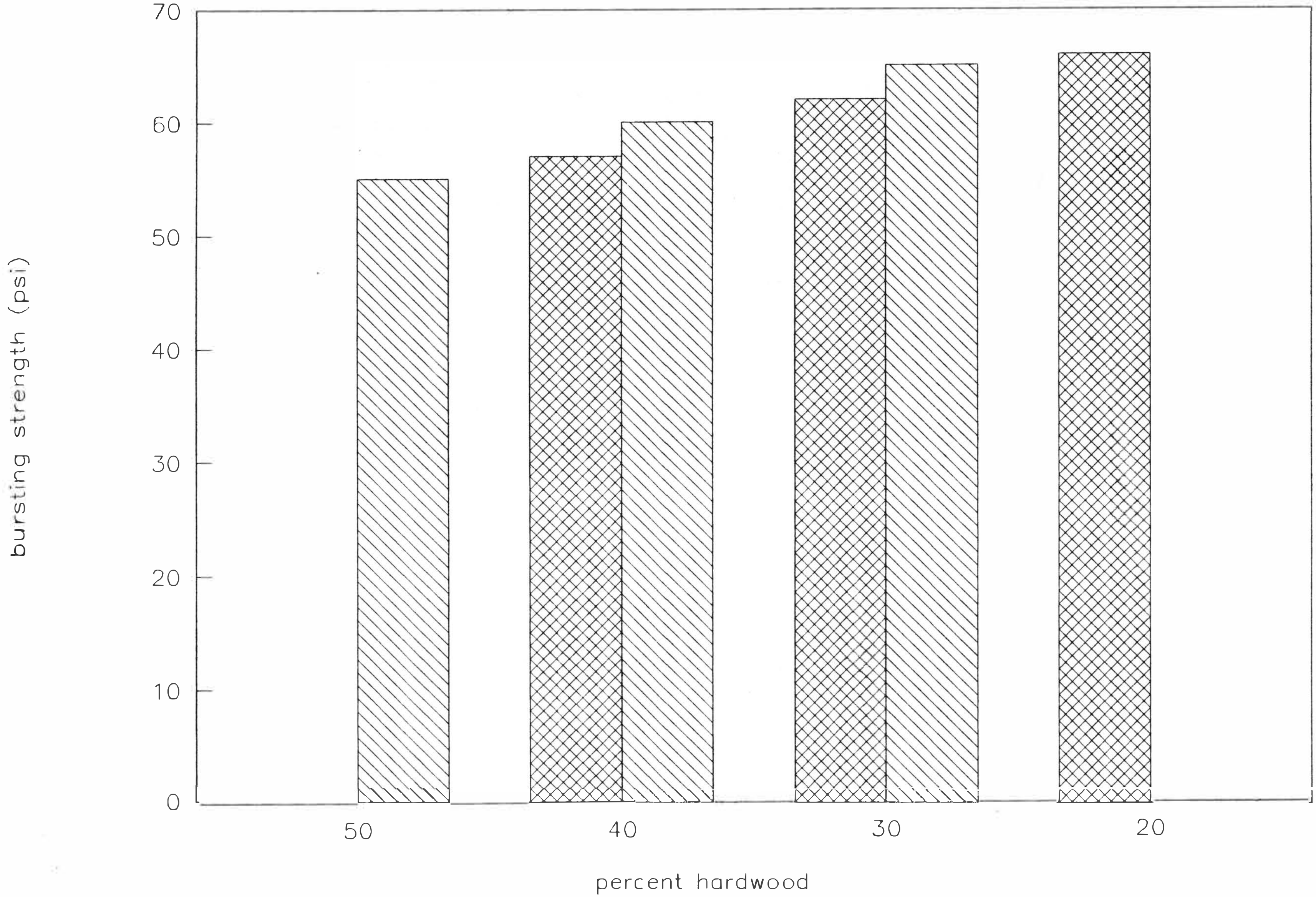


FIG. 2 TENSILE STRENGTH

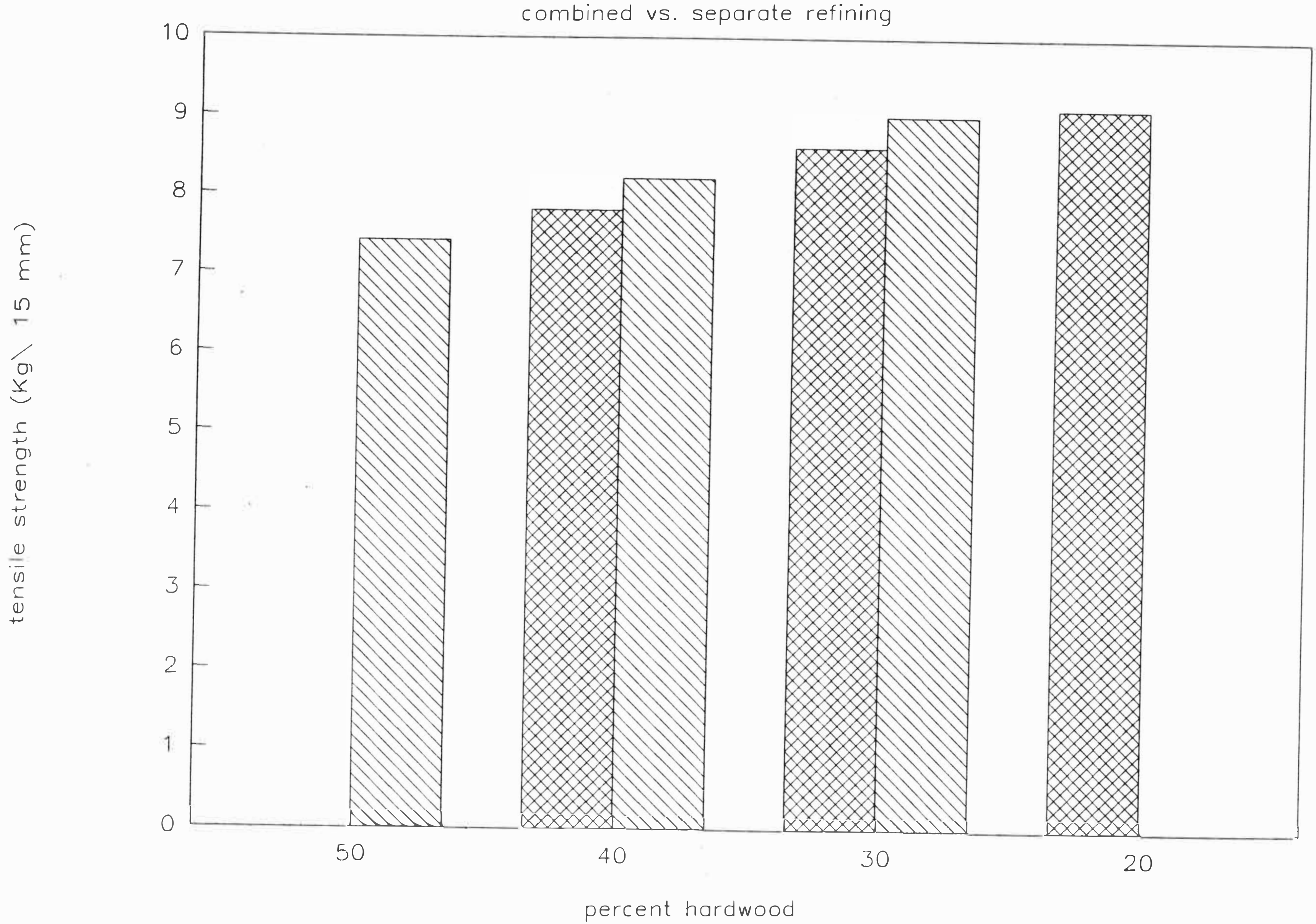


FIG. 3 TEARING STRENGTH

combined vs. separate refining

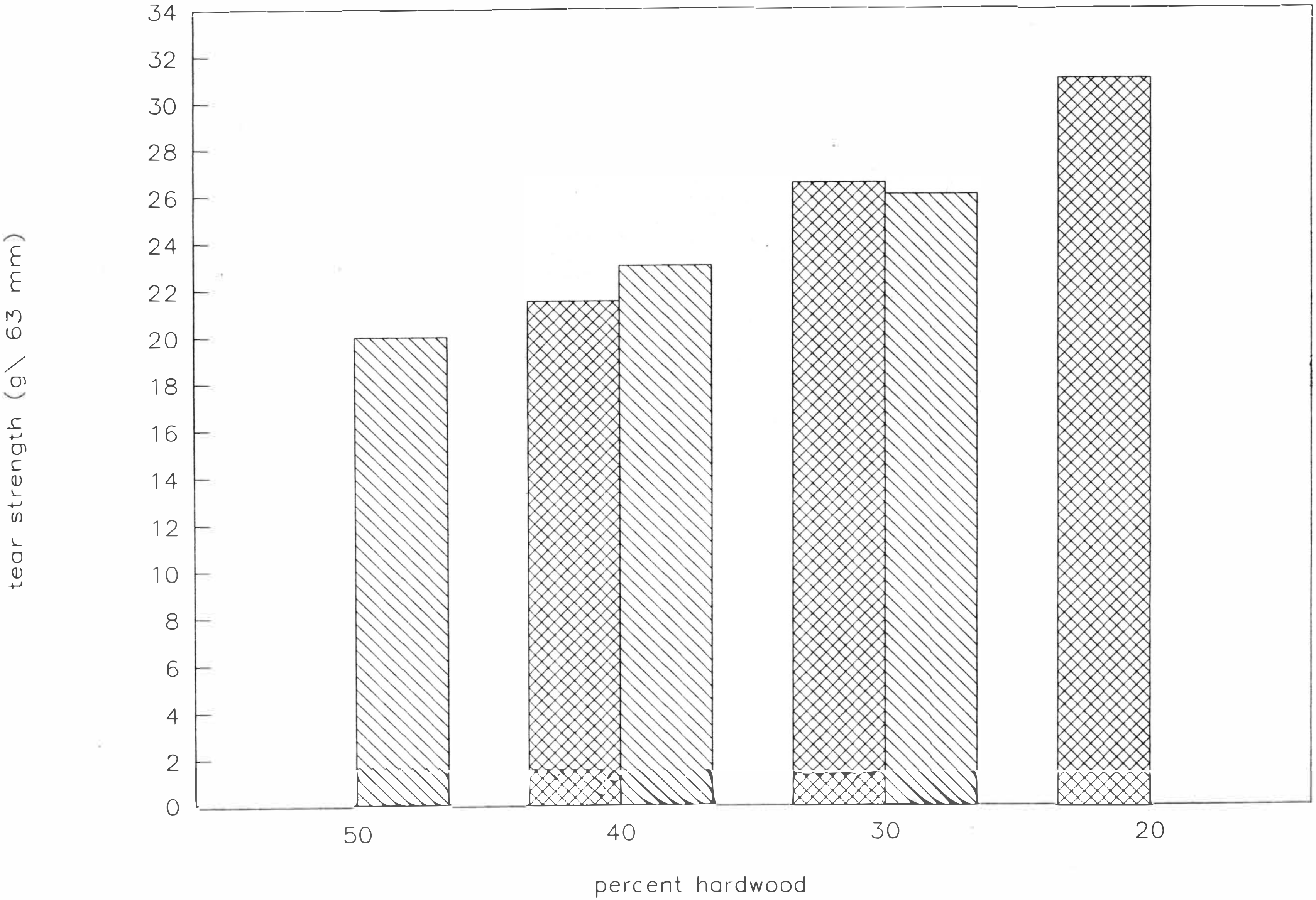
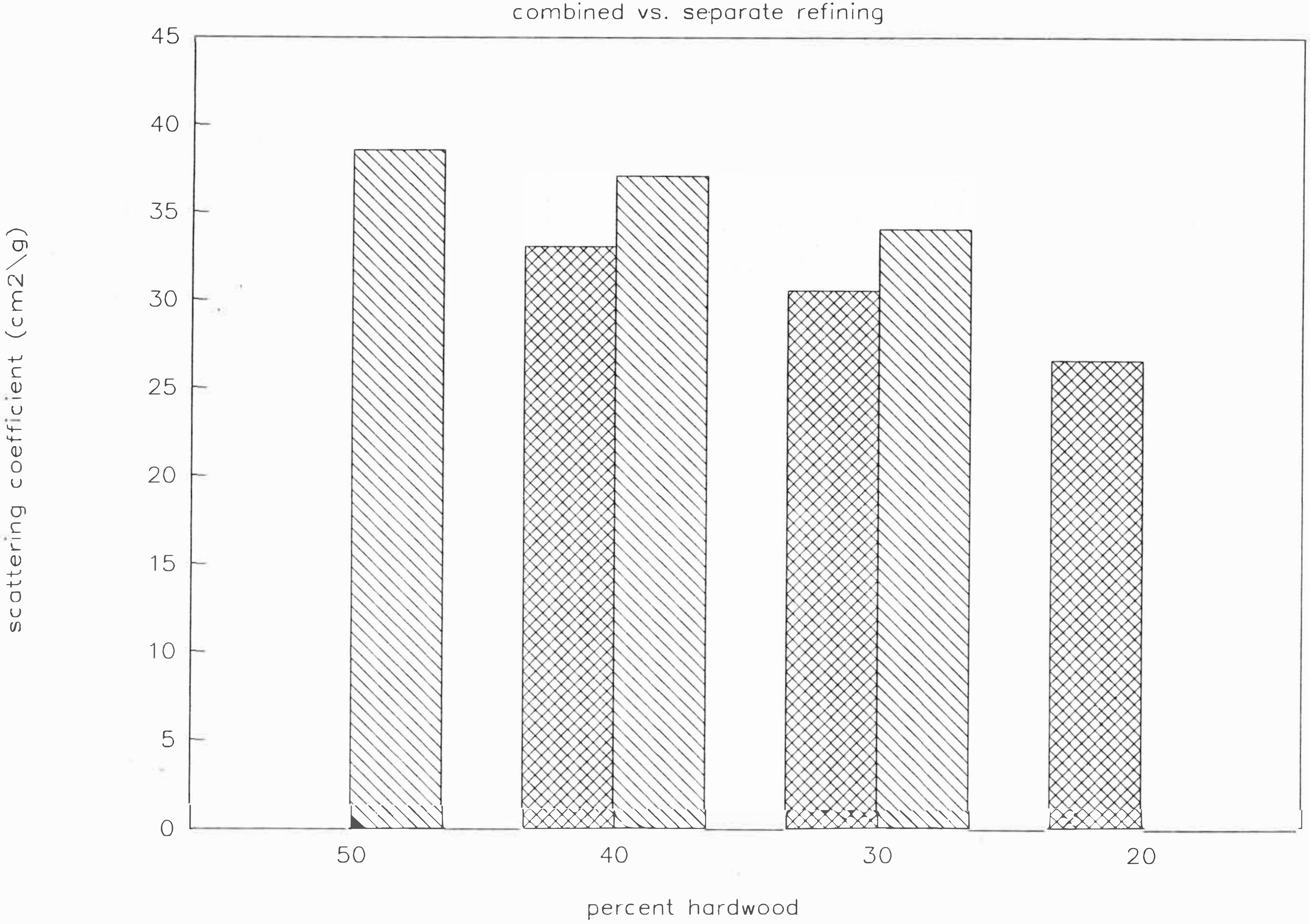


FIG. 4 SCATTERING COEFFICIENT



DISCUSSION

BURSTING STRENGTH

Figure 1, depicting bursting strength, leads to the conclusion that the bursting strength of a sheet can be increased by refining the hardwood and softwood separately. The resulting admixture, when compared to the control value, tended to have a six to seven percent (6%-7%) increase in bursting strength.

Hardwood fibers have a very short fiber length. If these fibers are over-treated a severe reduction in length may occur and strength values are strongly affected. By refining the hardwood alone, a low intensity refining was used and over-treatment may have been avoided. The increased bursting strength may possibly be attributed to the refining treatment of the hardwood.

As concluded by the Finnish Pulp and Paper Research Institute (3), softwoods develop a higher bursting value under high intensity refining. As these large fibers were treated cell wall fibrillation increased and more bonding sites were made available. More bonds lead to a stronger sheet

TENSILE STRENGTH

Figure 2, depicting tensile strength, leads to the conclusion that hardwood is capable of replacing softwood by refining the components separately. A seven to nine percent (7-9%) increase was achieved. In each case the sample that was refined separately had a higher resulting tensile strength. This trend is very similar to that found for the burst strength.

The tensile test is a measure of the force required to break a sheet of paper secured at both ends. A long fiber with a large surface\bonding area is ideal for this test. The high intensity refining of the softwood generates a high degree of fibrillation. This exposes a very large surface area and allows for a high degree of bonding, which in turn leads to a stronger sheet.

On the other hand, the low intensity refining of the hardwood furnish may have resulted in retention of fiber length. Hardwood fibers are very short. If the length of these fibers is reduced, severe damage to their strength may result. By retaining as much of the original fiber length as possible we maintain the strength these fibers have.

TEARING STRENGTH

Figure 3, depicting tearing strength, shows the data to be inconclusive on whether combined or separate refining is better for the development of tear strength. The general trend is the higher the softwood content the higher the tear strength.

The tear test measures the force required to continue a tear through a pre-determined distance. Long, fibrillated fibers have an extreme amount of surface area exposed. This may lead to increased fiber to fiber bonding in the sheet. Increased bonding leads to a strong sheet. Because the fiber length of the softwood is far greater than the fiber length of the hardwood, softwoods are capable of forming bonds with a higher number of other fibers, which may lead to higher tear results. This may be responsible for the trend of increasing tear results with increasing softwood content.

SCATTERING COEFFICIENT

Figure 4, depicting the scattering coefficient, leads to the conclusion that separate refining is ideal for achieving optical properties. At least a ten percent (10%) hardwood replacement for softwood may be obtained when this is the property of concern.

A tight, well formed sheet of paper may have more surfaces to reflect and refract light. The smaller hardwood fibers may help to fill in the voids of the sheet. As the voids are filled the test light now has more surfaces to bounce off. Which may lead to increased scattering coefficient.

By refining the softwood at a high intensity, a highly fibrillated fiber results. The lifted, and exposed fibrils greatly increase the surface area of the fiber. Hardwood fibers also, inherently, have a higher relative surface area than softwood fibers. The larger surface area of the sheet, allows for more refraction of the light. This may result in a higher scattering coefficient of the sheet.

CONCLUSIONS

A ten percent (10%) increase in hardwood content, while maintaining the strength properties was not met for bursting strength, tensile strength, and tearing strength. The ten percent replacement value was met for scattering coefficient by separate refining.

The results were very promising. With the exception of tearing strength, test results were better for the separately refined sheet when compared on the basis of like hardwood content.

By refining the hardwood and softwood separately the refining program can be modified to ideally match the needs of each. If the two types of fibers are refined together, compromises must be taken on both sides. When a low intensity refining is used on the hardwood, the fiber length may be retained. High intensity refining of the softwood leads to high degree of fibrillation. The increased amount of exposed surface area may allow for increased fiber to fiber bonding.

REFERENCES

(1) Giertz, H. W., "The influences of beating on the individual fibers", Refining Symposium 1980.

(2) Emerton, H. W., "Fundamentals of the beating process", TAPPI 1957.

(3) Levlin, J. E., "Some differences in the beating behavior of softwood and hardwood pulps", Refining Symposium 1980.

(4) Wahren, Douglas, "Refining of hardwoods and softwoods", IPC Technical Paper Series, No. 136 1983.

(5) Schuster, L. E., "Pulp Prices", telephone conversation, April 14, 1989.

(6) Levlin, J. E., "Characterization of the beating result", Refining Symposium 1980.

(7) Reeves, R. H., "Refining and refiner controls", TAPPI JOURNAL 1988.

(8) Corte, H. and Agg, S., "On the shortening of pulp fibers during refining", Refining Symposium 1980.

(9) Siewert, W. H. and Selder, H., "Economic use of energy in pulp refining", Refining Symposium 1980.

(10) Fox, T. S., "Inside a disk refiner", Refining Symposium 1980.