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The Effect of Structure on the Stiffness of Cylinder Board

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THE EFFECT OF STRUCTURE ON THE STIFFNESS OF CYLINDER BOARD

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ABSTRACT

The purpose of this thesis was to study the effect of board structure on the stiffness of cylinder board. This area was chosen as stiffness is one of the most important attributes of cylinder board and the literature survey revealed that very little work has been done in this area.

A new method for making multi-ply boards in the laboratory was developed. These boards were made in the British Sheet Machine under constant head and avoided the problems associated with wet-pressing individual plys together. This method was found to give reproducable results.

At certain compositions, multi-ply boards made with kraft liners and groundwood filler had stiffness values that were greater than kraft or groundwood alone at the same caliper.

Stiffness values were converted to bending modulus as it was felt that this would remove the effect of caliper. However, it was found that it does not accomplish this.

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INTRODUCTION

STATEMENT OF THE PROBLEM

The purpose of this experimental program is to study the effects of changes in board structure on the stiffness of a cylinder board. According to Casey (1) stiffness is the most important property in folding boxboards, since the utility of the box depends upon its ability to resist bulging when filled.

This work will explore board structure to determine how pulps may be used most effectively in forming a cylinder board of maximum stiffness. It will be accomplished in three phases. These include (1) developing a method for forming a multiply board on a laboratory sheet machine, (2) examining the stiffness of the boards formed, and (3) evaluating the date obtained.

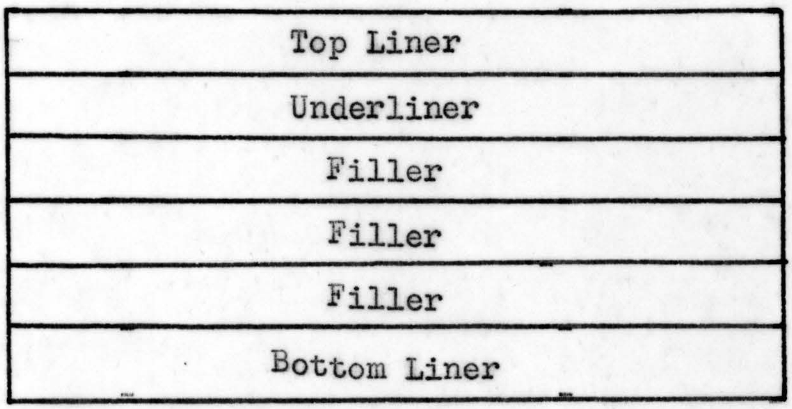
CYLINDER BOARD STRUCTURE

Cylinder boards and paper boards which are composed of several plys which have been wet-pressed together. Five to eight plys are common. The top ply and the one just below it are called the "top liner" and "underliner" respectively. The bottom ply is called the "bottom liner". The plys between the underliner and the bottom liner are called "filler". A typical board is shown in Figure 1. (2).

Most boxboards have calipers in the range of .020 and .024 inches with basis weights of 70 to 85 lbs/1000 square feet.

Figure 1

A Typical Cylinder Board



Generally, the furnish of a board will include repulped waste paper in the filler plys, for bulk and caliper, and a chemical pulp in the top liner, underliner and bottom liner. Many boards are made with bleached chemical in the top liner and underliner for aesthetic purposes. The bleached underliner prevents show-through. The chemical pulp is necessary as the top and bottom liners undergo maximum strain, as explained later, and the chemical pulp is stronger than groundwood.

STIFFNESS

Stiffness is that property of a material that resists bending and flexing. This property is dependant upon the modulus of elasticity and moment of inertia (4).

The moment of inertia is an expression of the internal resisting moment that is set up in the body when subjected to a bending moment (5). The moment of inertia $\underline{I}$ of a body with rectangular cross-sectional area is $\underline{bh^3}/12$ where $\underline{b}$ is the length of the base and $\underline{h}$ is the height or thickness of such a body.

From Equation I, it is apparent that stiffness will vary with the cube of the thickness. This is true for homogenious materials but for paper there are limitations. Smith (6) found that rigidity increases with the cube of caliper at constant density and with the square of caliper at constant

weight. Rigidity varies with density at constant caliper.

The modulus of elasticity is another term for Young's Modulus E which is the ratio of unit stress to unit strain. A stress is the internal force resisting an external load. The resulting changes in form and dimensions of the body are called deformations or strains. As modulus of elasticity increases then for any particular strain, the stress applied must necessarily be increased. According to Kellicutt (7), modulus of elasticity is one of the most significant properties of corrugated liner board.

Bending moment is the product of the load times the distance from the supported end of a cantilever beam.

Stiffness tests fall into three basic catagories according to Casey (1). Type one measures the force required to bend the paper through a given angle, type two measures the angle through which the paper is bent with a given load, and type three measures the angle through which the paper bends under its own weight.

The Taber instrument has been chosen for this work for two reasons. It is fairly easy to operate correctly, and the values for the stiffness are not arbitrary. For this reason, the modulus of elasticity may be calculated for the board in question.

The Taber instrument uses a specimen $1\frac{1}{2}$ by 23/4 inches

which is fastened to a clamp on a pendulum. A force is applied to the lower end of the specimen by rollers attached to a power driven disk, and the specimen is deflected as a cantilever beam. The end point of the test is when the specimen has been deflected a predetermined amount. See Figure 2. To compensate for curl, the test is run in both directions and averaged. Refer to Taber Bulletin 4506-10M for further details.

A cantilever beam composed of a homogeneous, elastic material will deflect under a load P in accordance with Equation (1).

$$Y = PL^3/3EI \qquad (1)$$

Y = deflection

P = load

L = length of span

E = modulus of elasticity

I = moment of inertia

Rearranging Equation (1) and dividing both sides by the width b, Equation (2) results.

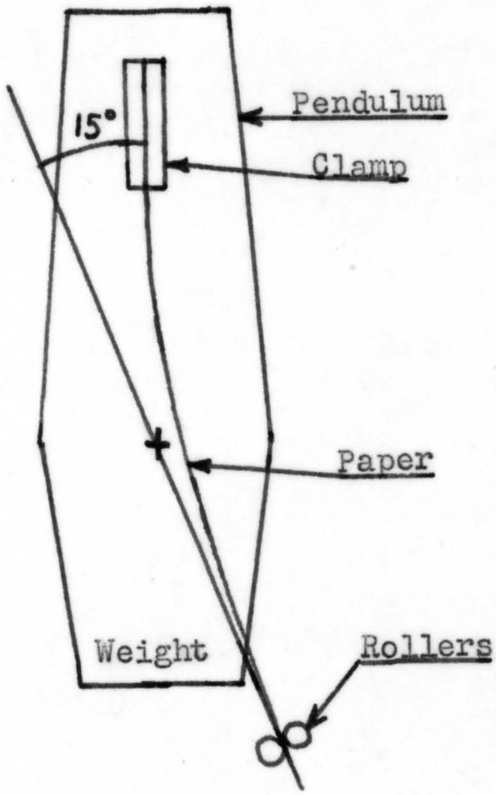
$$EI/b = PL^3/3yb. \qquad (2)$$

The term EI/b has been defined as the flexural stiffness per unit width.

The value read from the Taber instrument is PL, the bending moment, with units of gram centimeters which must be

Figure 2

Schematic Drawing of Taber Stiffness Tester



converted to English units for use in Equation (2). When the dimensions of the beam are known, then the flexural stiffness may be determined. When this is divided by the moment of inertia I, the modulus of elasticity E is known. Since we have divided by I, the effect of caliper has been removed from the equation (4).

For paper, these formulas have certain limitations. These formulas are only strictly applicable to homogeneous materials which have moduli of tension and compression that are equal.

The Gurley instrument measures the bending moment the paper can withstand in both directions by deflecting a small weighted pendulum (1).

The Clark tester is a measure of the critical length of a two inch strip of paper that will just fall over when the instrument is rotated ninety degrees. The length is adjusted so that an angle of ninety degrees exists when the paper swings from one side to the other and vice versa (1).

For heavy boards, a simple beam test may be used. The board is mounted on rollers and a stress is induced at a constant rate. The stress is then plotted against strain (1).

HISTORICAL BACKGROUND

Root (8) claims that paper board may be treated as an

engineering material. Once the modulus of elasticity is known, maximum strength may be computed. The calculated results usually agree with test data within six percent.

Trosset and Aiken (3) have shown that to increase stiffness of a board at constant caliper, it is more economical to place the stiffest material on the outside as these plys undergo maximum tension and compression.

ANALYSIS OF THE PROBLEM

FACTORS AFFECTING THE STIFFNESS OF A BOARD

Factors affecting the stiffness of boards may be divided into two catagories; fiber properties and board properties.

1. Fiber properties
   a. Fiber species
   b. pulping method
   c. chemical composition
   d. beating time
2. Board properties
   a. moisture content
   b. density
   c. caliper
   d. basis weight
   e. formation
   f. sizing and other additives
   g. ply arrangement (4)

The term ply arrangement refers to the relative positions of the various plys in the board. The plys may be arranged in a number of ways for any particular board but for the stiffest board, the most rigid material should be the top and bottom liner.

Trosset and Aiken (3) have stated that to produce a board of maximum stiffness at constant caliper, it is most economical to increase the stiffness of the outermost plies since they com come under maximum strain. This may be illustrated by the following example.

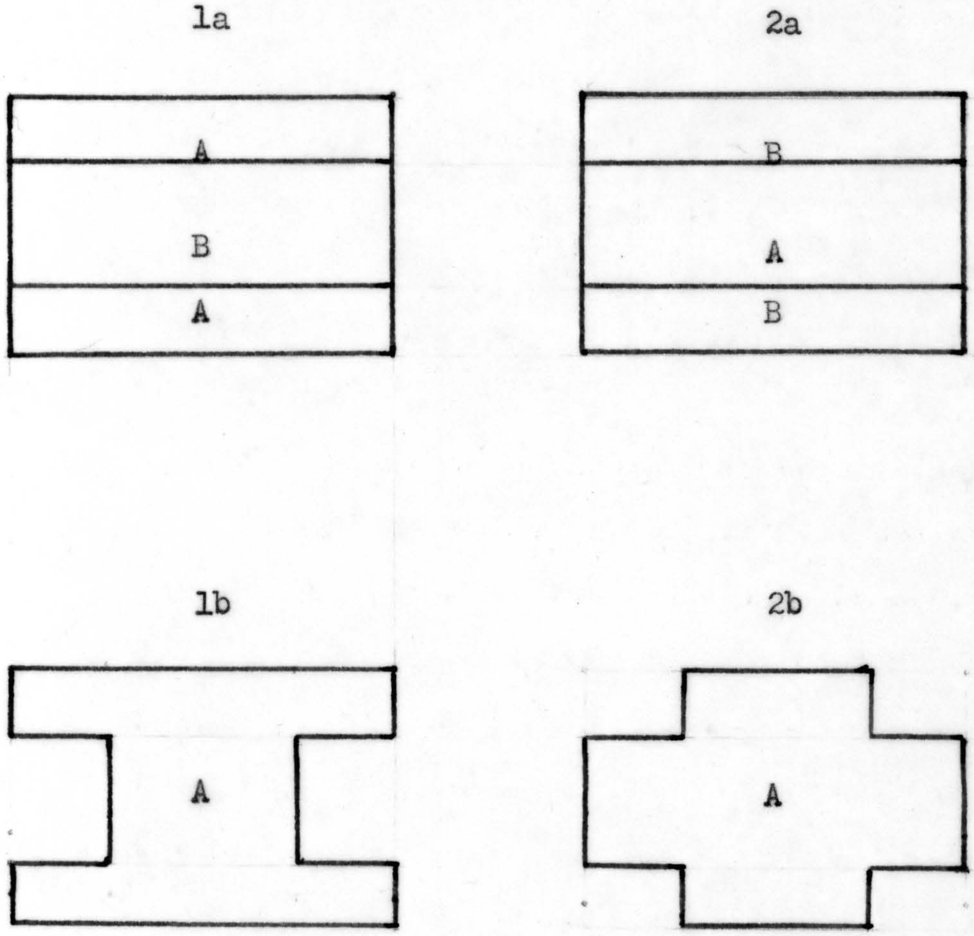
If we have two structures with the same cross section and $E_B = 2E_A$, then the flexural stiffness of B will be twice that of A since the moments of inertia are the same. Likewise, from Equation (1), they will have the same stiffness if the width of beam B is one half the width of beam A.

From this discussion, it is apparent that one material may be substituted for another provided the moment of inertia is changed to compensate for the differences in Young's Modulus.

If we have two three-ply beams such as those which are shown in Figure 3a in which material A has a higher Young's Modulus than material B, then these beams may be represented as being composed of material A as shown in Figure 3b. Since beam 1 now has a higher moment of inertia than does beam 2 and since Young's Modulus is now the same for both beams, beam 1 will be stiffer.

Figure 3

Beam Comparison



Three problems exist in the area of stiffness and boards. The first is that all stiffness tests bend the paper beyond its elastic limit and, for this reason, the stiffness readings are time dependent.

Secondly, there is no method available for producing multi-ply handsheets in the laboratory except by wet-pressing handsheets together after they have been formed. A method now has been developed and will be discussed under experimental procedures.

Thirdly, it is believed that the tension and compression moduli of papers are not the same. This causes problems in the evaluation of the data as the neutral axis, that point which is neither under tension or compression, will shift when the board is flexed in the opposite direction.

EXPERIMENTAL PROCEDURES

A new method for making multi-ply boards has been developed in the course of this study. These boards are made in the British Sheet Machine under constant head. This method eliminates the problems associated with board formation by wet-pressing individual plies together,

Holes, 7/32 inches in diameter, were drilled in three handsheet drying plates. These holes duplicate the pattern found on the dasher for the British Sheet Machine.

These plates were then suspended in the hinged cylinder above the wire screen by three glass rods. The distances of these plates from the wire screen were 5 7/8, 7 3/8, and 9 1/8 inches. These plates served to distribute the flow of pulp and water in the cylinder and also help control flocculation.

The cylinder was first filled with water. Once the cylinder was filled, water was then allowed to flow into the top of the sheet machines through a hose. The proper level of water in the mold was controlled by the drain valve at the bottom. In this manner, a dynamic constant head could be maintained.

As an example of the procedure used in forming a board, let us suppose that we would like to produce a two-ply board from pulps A and B. Water is continuously run in and drained out of the cylinder as the required amount of pulp A is added. The process is continued until pulp A has formed a sheet on the wire. Then pulp B is added and the incoming water is shut off and the cylinder is drained. A two-ply board, of course, results.

It was found in the early stages of board formation that a chemical pulp such as kraft will flocculate. These masses of fiber were often large enough to plug some of the holes in the discs, thus giving poor formation and uneven caliper.

It was decided that the best solution would be to dilute the pulp slurry to a very low consistency so that the individual fibers would not be close enough to flocculate. This was accomplished by a plywood headbox which was six inches wide and deep and eleven inches long. The box contained four partitions forming five compartments. The partitions were arranged in such a manner that the pulp slurry had to flow over one and then under the next. See Figure 4.

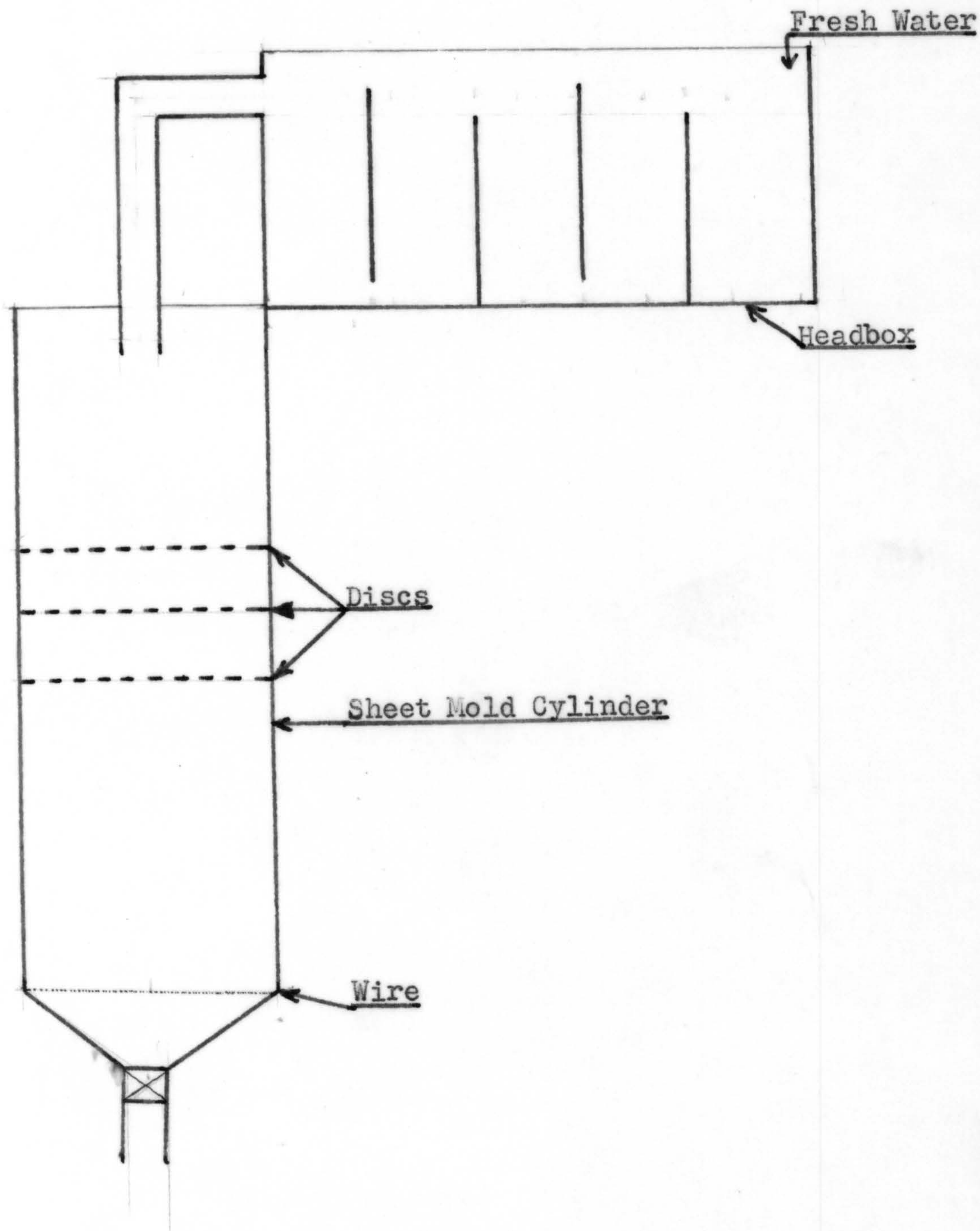
In operation, the headbox was mounted over the sheet mold. The incoming water hose terminated in the last compartment of the headbox and created a great deal of turbulence. The pulp was slowly added to this compartment and was thoroughly dispersed by the time it flowed into the sheet mold. This gave a low enough consistency to eliminate flocculation of the kraft pulp.

Once a board had been made, it was pressed and dried in accordance with TAPPI method T205 m-58.

The sheets were stored for 40 hours at 73°F and 50% relative humidity before any testing was carried out. All testing was performed under the same conditions. The caliper was then checked for each sheet and the sheet was cut into four test specimens for stiffness determination. Stiffness was determined on the Taber Stiffness Tester in accordance with Taber Bulletin 4506-10M.

Figure 4

British Sheet Mold With Headbox and Discs in Place



Two pulps were used to form all multi-ply boards. Bleached Espanola Kraft pulp was used for the top and bottom liner while conventional groundwood was used as filler.

Both pulps were disintegrated in a TAPPI disintegrator and allowed to stand for a minimum of 20 hours.

At that time the consistency was checked. Curves were made, at the beginning of the laboratory work, of sheet weight versus caliper for both the kraft and groundwood pulps. From this information, the amount of pulp necessary to produce the caliper desired in each ply could be determined.

PRESENTATION OF DATA

TABLE I

BOARDS OF CONSTANT CALIPER FILLER AND INCREASING TOTAL CALIPER

Caliper in.	Stiffness	Bending Modulus, p.s.i. x10^5
.0164	87.0	2.30
.0177	121.5	2.56
.0189	143.0	2.48
.0221	205.5	2.23
.0223	204.5	2.16
.0241	270.0	2.26
.0257	325.0	2.24
.0267	346.0	2.12
.0279	397.0	2.13
.0293	435.0	2.02
.0310	514.0	2.02

BOARDS OF CONSTANT CALIPER LINERS AND INCREASING TOTAL CALIPER

Caliper in.	Stiffness	Bending Modulus, p.s.i. x10^5
.0123	36.0	2.27
.0134	47.3	2.32
.0144	56.9	2.22
.0165	77.6	2.02
.0171	80.3	1.88
.0178	104.4	2.18
.0182	116.3	2.26
.0193	135.6	2.22
.0201	147.5	2.12
.0211	145.0	1.81

BOARDS OF CONSTANT TOTAL CALIPER WITH VARYING FILLER AND LINERS

Composition, % groundwood	Caliper, in.	Stiffness	Bending Modulus, p.s.i. $\times 10^5$
0	.0206	158.3	2.12
10	.0201	177.5	2.56
20	.0199	176.7	2.63
30	.0203	183.3	2.56
40	.0199	149.2	2.22
50	.0197	160.0	2.46
70	.0191	130.6	2.20
80	.0191	123.1	2.07
90	.0191	118.1	1.99
100	.0198	117.5	1.78

ALL-KRAFT BOARDS

Caliper, in.	Stiffness	Bending Modulus, p.s.i. $\times 10^5$
.0162	78.8	2.17
.0194	134.0	2.15
.0213	176.0	2.13
.0242	226.0	1.87
.0267	293.0	1.80
.0297	355.0	1.57

DISCUSSION OF RESULTS

The first set of boards was made to study the effect of increasing the total caliper with a constant-caliper filler. The caliper of the top and bottom liners, of course, increased. Each board was symetrical; that is, the top and bottom liners were of equal caliper.

Bleached Kraft pulp was used for the top and bottom liners while conventional groundwood was used as filler. Groundwood caliper was .0129 inches while total caliper varied from .0164 to .0310 inches.

From Table I, it can be seen that stiffness increases with caliper. This would be expected since stiffness increases exponentially with caliper.

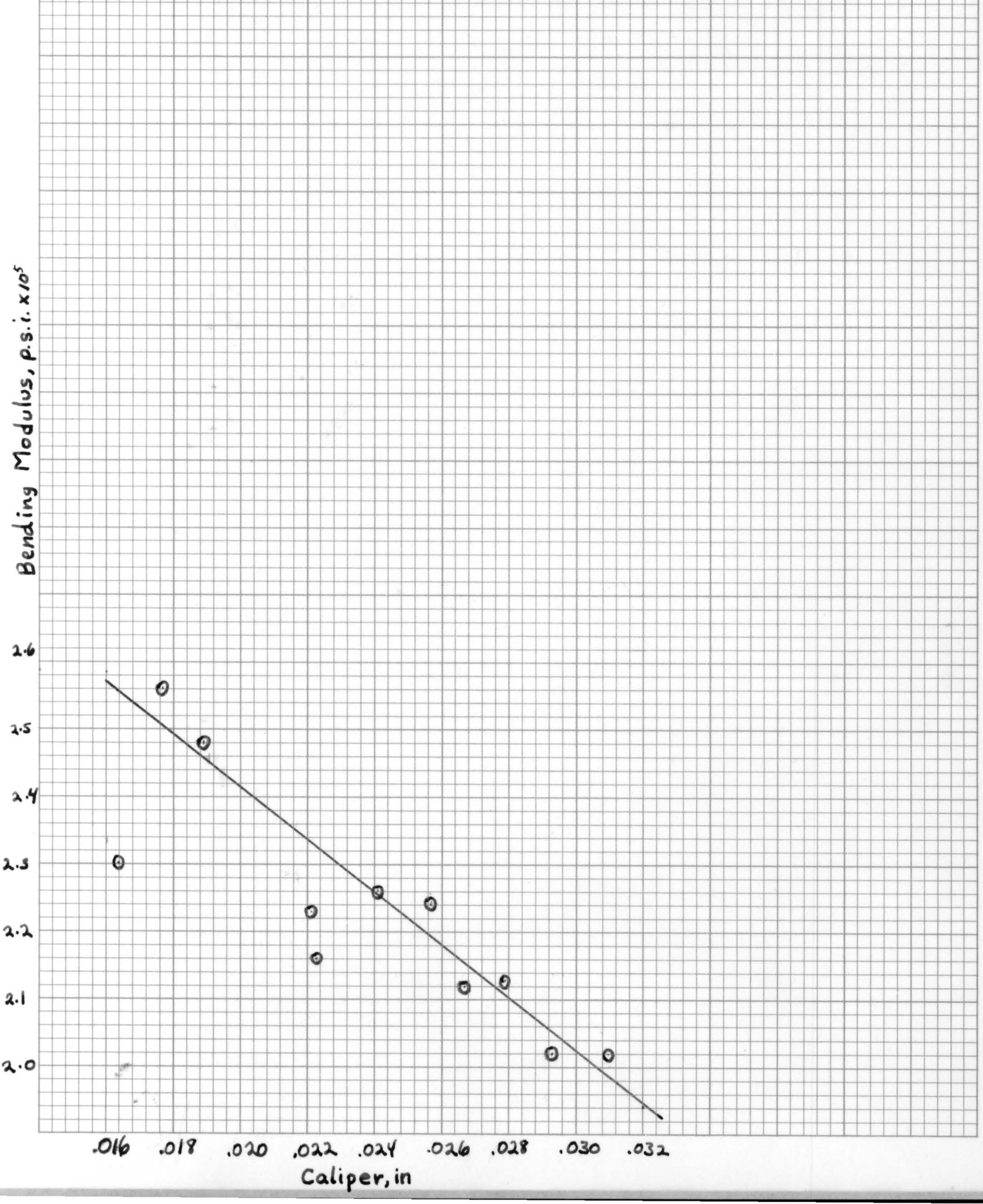
Bending modulus decreases with caliper as shown in Figure 5.

The second set of boards was made to study the effect of increasing the caliper of the filler with constant-caliper liners. Total caliper would, of course, increase. Again, each board was symetrical. The caliper of each liner was .0030 inches while total caliper varied from .0123 to .0211 inches.

As before, as the caliper increases, stiffness increases but the curve exhibits a change in slope at a caliper of

Figure 5

The Relationship Between Bending Modulus and Caliper For Boards Made With Constant Caliper Filler and Increasing Total Caliper



.0171 inches (Figure 6). The bending modulus curve (Figure 7), exhibits two peaks with the break between the peaks corresponding to the change in slope in Figure 6. No conclusion could be drawn from these data.

The third set of boards was made to study the effect of varying the board structure at a constant total caliper.

Again, three-ply boards were made with the caliper of the top and bottom liner increasing from 0 to .020 inches while the caliper of the filler decreased from .020 to 0 inches. Total caliper remained at .020 inches.

Since the caliper was essentially the same in all cases, bending modulus and stiffness follow corresponding curves.

The bending modulus curve (Figure 8) exhibits a peak at about 20%, by caliper, groundwood. This stiffness is about 25% greater than the bending modulus of an all-kraft board.

These results do not agree with the results for the sheets made with constant caliper filler and increasing caliper top and bottom liner. Those boards had groundwood caliper percents varying from 79 to 42%. Since we were increasing the kraft content, then the bending modulus should increase rather than decrease and should follow the results as shown in Figure 8.

Figure 6

The Relationship Between Stiffness and Caliper For Boards Made With Constant Caliper Liners and Increasing Total Caliper

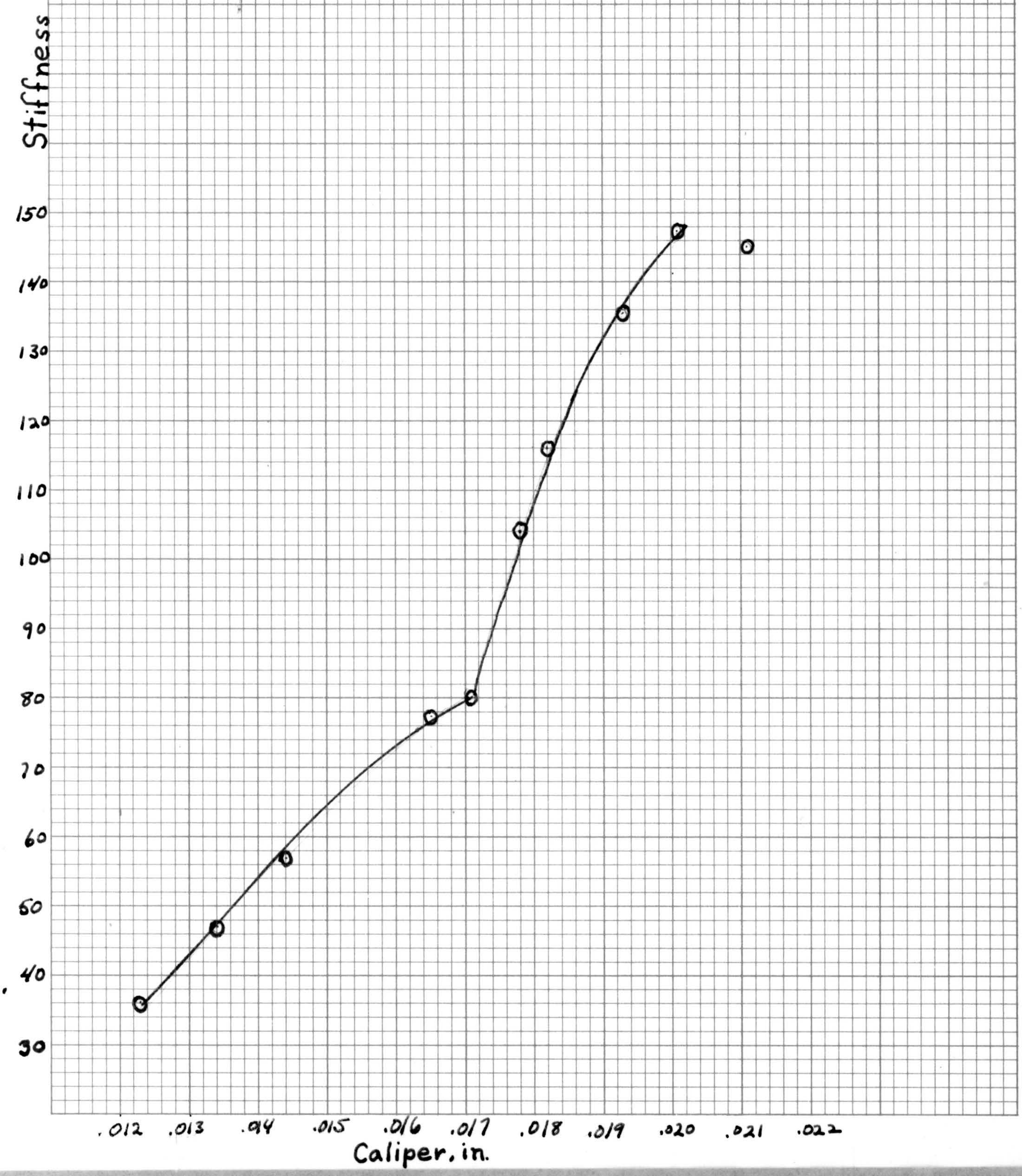


Figure 7

The Relationship Between Bending Modulus and Caliper For Boards Made With Constant Caliper Liners and Increasing Total Caliper

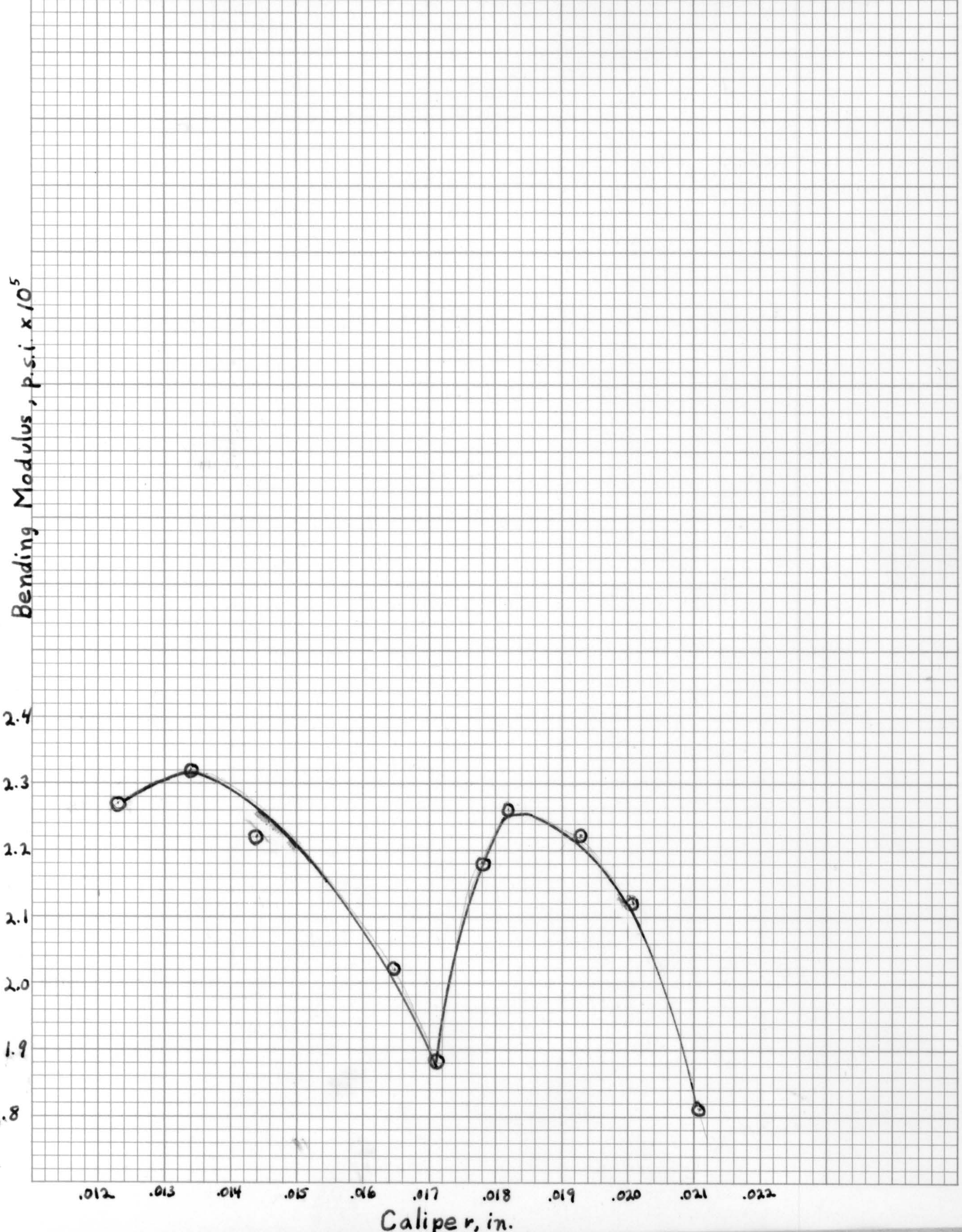
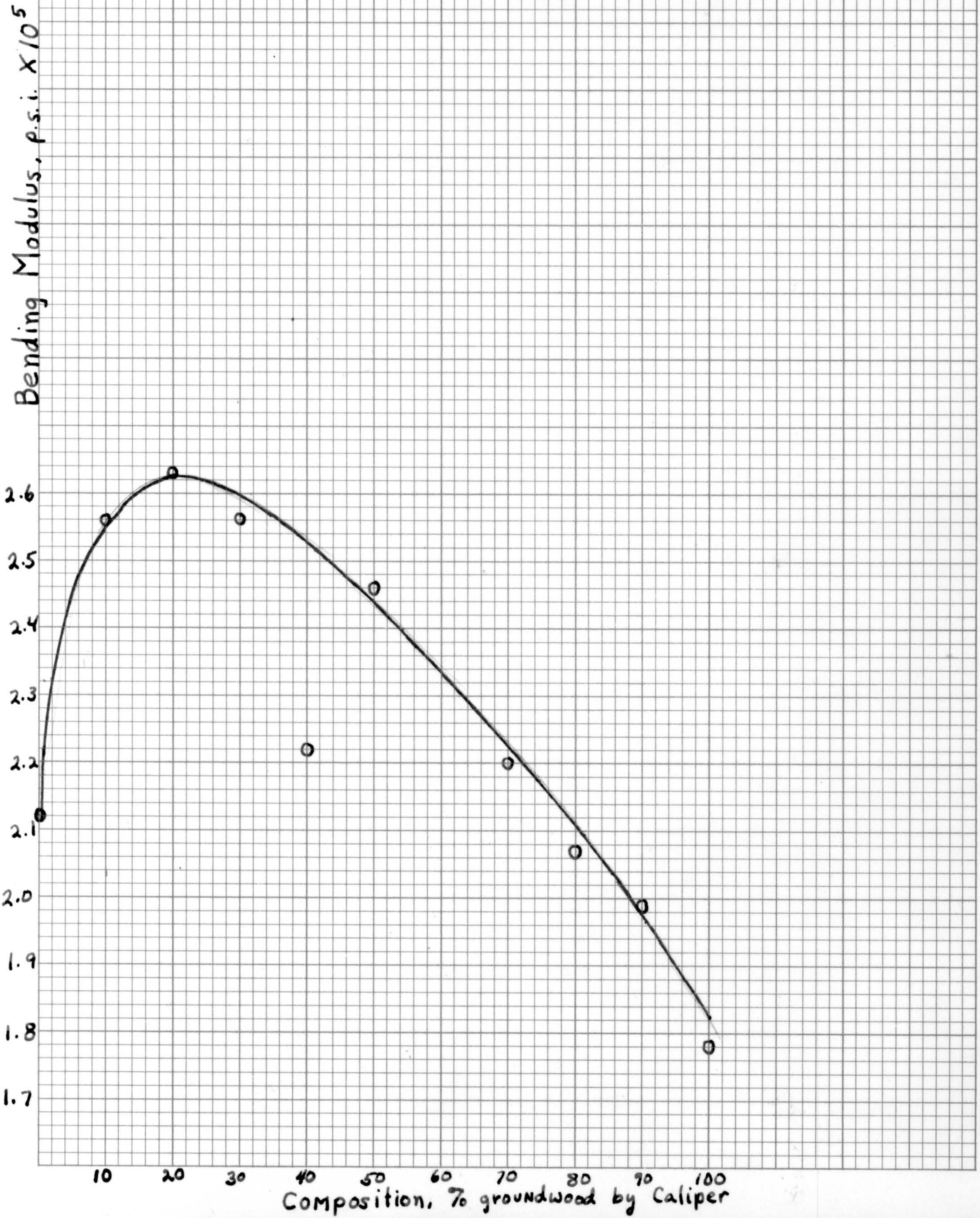


Figure 8

The Relationship Between Bending Modulus and Percent Groundwood

For Boards Made With Constant Caliper and Varying Structure



Since the only difference between the two sets was that one had increasing caliper while the other had constant caliper, the discrepancy must have been in the treatment of results. Bending modulus apparently does not remove the effect of caliper.

To test this theory, all-kraft boards were made with caliper increasing from .0162 to .0297 inches. Since all boards were made with the same material, bending modulus should be the same in all cases. Bending modulus was found to decrease with caliper and thus introduced an error into the bending modulus calculations for the set with varying caliper. See Figure 9.

In Figure 10, the stiffness of the boards made with constant-caliper filler and increasing caliper top and bottom liners was plotted against total caliper. Also on the same graph, the stiffness of all-kraft board was plotted versus caliper. Notice that the multi-ply board is stiffer than kraft board on the right side of the curve for any particular caliper and that the two curves intersect at a caliper of about .0160 inches. At this point the multi-ply board has a composition of $\frac{12.9}{16.0}$ groundwood or 80.5%. In Figure 8, a multi-ply board of 77% groundwood has the same stiffness as an all-kraft board. Thus Figure 8 and Figure 10 substantiate

Figure 9

The Relationship Between Bending Modulus and Caliper For All-Kraft Boards Made With Varying Caliper

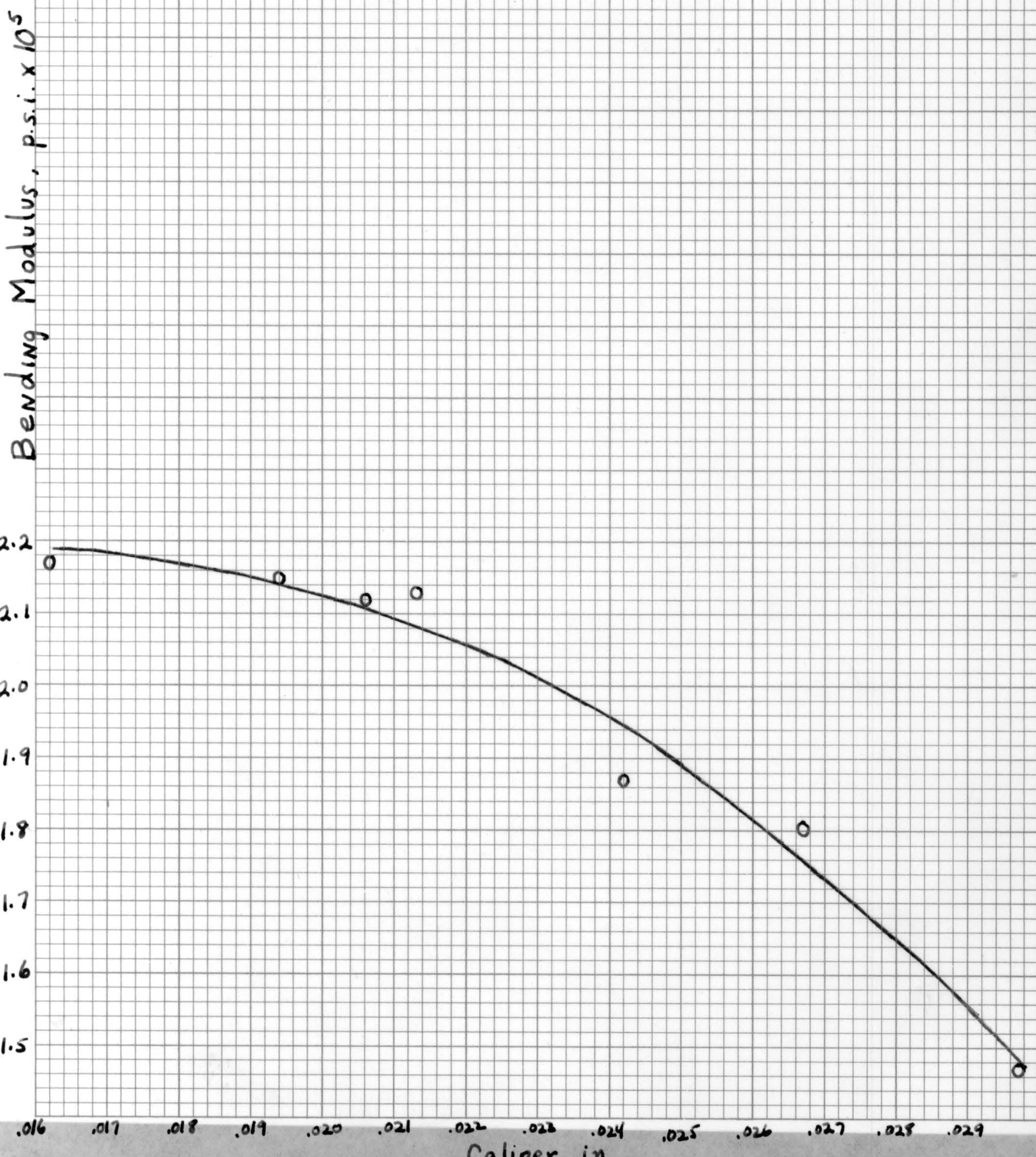
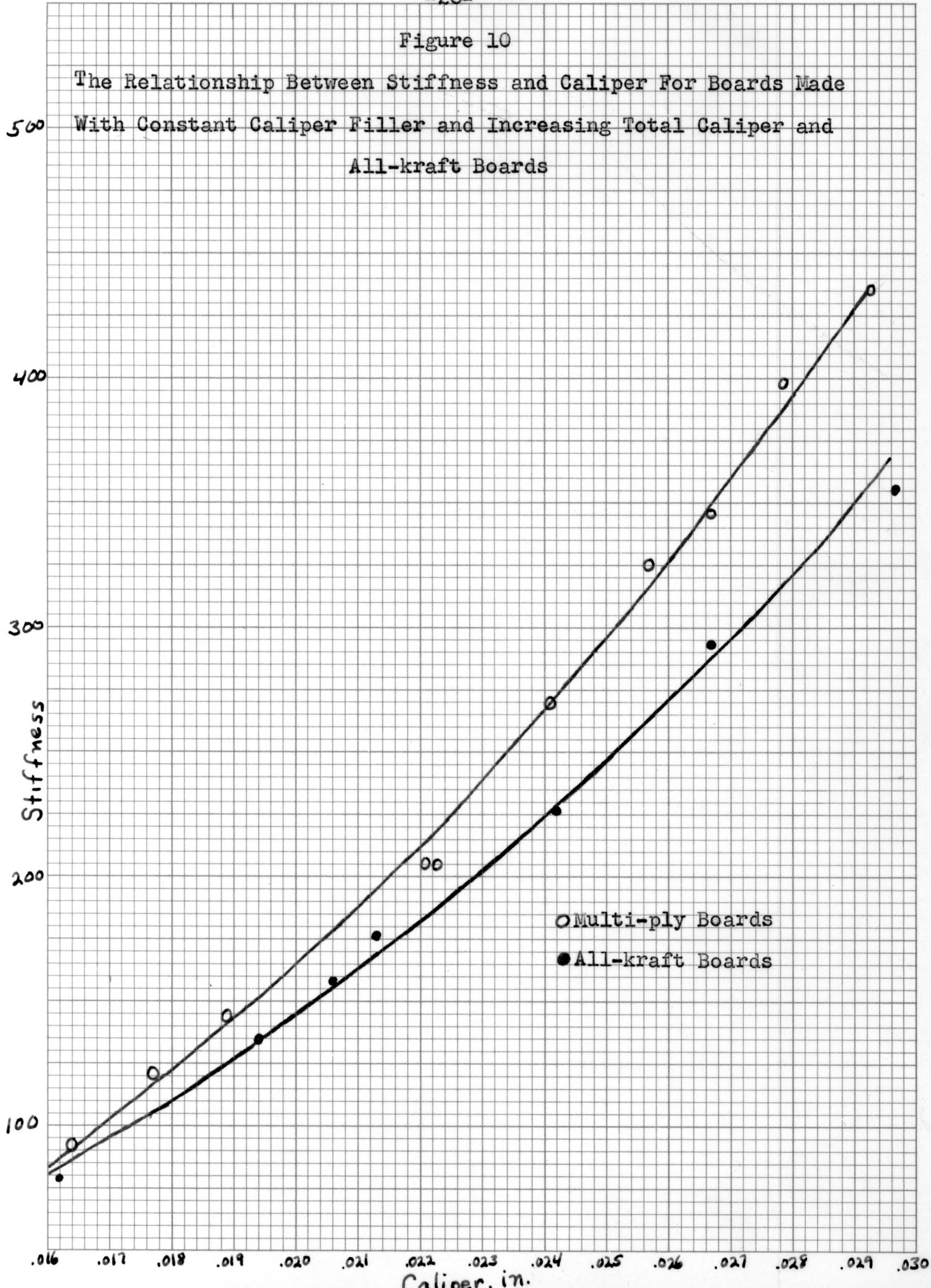


Figure 10

The Relationship Between Stiffness and Caliper For Boards Made With Constant Caliper Filler and Increasing Total Caliper and All-kraft Boards



each other.

These graphs show the possibility that a multi-ply board can have a greater stiffness than either kraft or groundwood alone at the same caliper.

CONCLUSIONS

1. Multi-ply boards can be made by the new method that was developed in the course of this study. These boards have good formation with low deviation of caliper, and can give reproduceable results.

2. Sheets prepared with constant-caliper filler and increasing caliper of top and bottom liner exhibit increasing the caliper of an all-kraft board. The multi-ply sheets showed the possibility that such boards can have greater stiffness than kraft boards at the same caliper.

3. Boards made at constant overall caliper with varying caliper of the kraft liners and groundwood filler exhibit a peak in stiffness readings that is higher than either kraft or groundwood alone at the same caliper.

4. Stiffness calculated in terms of bending modulus does not remove the effect of caliper from the results. Bending modulus was found to drop with increasing caliper.

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