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The Effect of Fiber Distribution upon Stiffness of Paper Board

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THESIS

THE EFFECT OF FIBER DISTRIBUTION UPON STIFFNESS OF PAPER BOARD

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ABSTRACT

THE EFFECT OF FIBER DISTRIBUTION UPON STIFFNESS OF PAPER BOARD

This problem was approached by making multiply handsheets in the laboratory with various equicaliper ply arrangements of bleached sulfite pulp and overissue news, testing these sheets under standard conditions, and analyzing the data.

The handsheets were made by passing two Noble and Wood formed fiber mats placed face to face through an unloaded wet press. After removal of a forming wire a third ply could be added, followed by a second wet pressing. Upon constructing the sheet in this manner final wet pressing was accomplished by passing the multiply sheet through the loaded wet press. Sheets so formed were dried on the steam drum, conditioned, and tested.

Sets of three-ply and five-ply sheets having various ply configurations were evaluated. A second set of five-ply sheets showed the effect of replacing a portion of stock with bleached kraft pulp in any one ply of a basic arrangement.

From the foregoing, the following conclusions were made:

1) The method employed for making multiply sheets gave accurate and reproducible results.

2) The modulus of elasticity and the moment of inertia of the liner plies are of primary importance in overall sheet stiffness.

3) The filler stock has the basic function of separating the liners causing the liner plies to have high moment of inertia values.

4) Upgrading to increase stiffness at constant caliper will have maximum results when done to the liner furnishes.

THE EFFECT OF FIBER DISTRIBUTION UPON STIFFNESS OF PAPER BOARD

Stiffness represents an area of major importance in the manufacture, conversion, and use of almost all grades of paperboard. In the light of present day advances in production and processing, coupled with increased use requirements, the characteristic of stiffness is of increasing importance.

The study undertaken in this work delt with investigation of the effect of fiber distribution, or ply position, on stiffness. This will primarily be of interest to those concerned with multiply board, however, the theory will apply to all types of board manufacture. A study of this nature is so basic that an understanding of stiffness whould be benificial to anyone concerned with the area of paper technology.

Clark (1) defines stiffness as the ability of paper to support its own weight. He represents this defination as:

$$\frac{(L)^3}{100}$$

where L is the overhang of a standard sized sample clamped horizontally at one end.

Casey (2) defines stiffness with the formula:

$$\frac{ET^2}{12} \times \frac{W}{L^2}$$

where E is Young's Modulus

W is the sample width

L is the sample length

and T is the sample thickness.

Yet another defination of stiffness that is more popular is that given by Carson(3). Carson defines stiffness as the bending moment per

unit speciman width and per unit speciman curvature at the torque axis. This may be expressed as:

$$\frac{mL}{3b} f(\emptyset)$$

where m is the bending moment at the torque axis

L is the bending length

b is the speciman width

and $\emptyset$ is the bending angle.

This defination by Carson agrees with that by Sharman (4), and with the defination of flexural rigidity given by Peirce (5).

For the area of work undertaken here, stiffness may be defined simply as the resistance of a piece of paperboard to bending or flexing. Stiffness is directly dependent upon the modulus of elasticity, E, and the moment of inertia, I, and can be expressed as:

$$\text{Stiffness} = E \times I.$$

The modulus of elasticity, also called Young's modulus, the bending modulus, and the coefficient of elasticity, may be defined as a stress-strain ratio. That is, it may be defined as the force, (the stress), required to stretch a sample of unit size a unit length, (the strain). Materials such as rubber and some plastics that stretch with a small force have a low modulus and therefore a low stiffness. At the other extreme, materials that do not stretch easily, such as most metals, have a high elastic modulus and also high stiffness. Wood pulps will fall between the two extremes cited in modulus of elasticity and in stiffness values. Modulus of elasticity values are given for several pulps at various freeness levels in Table I on page 6.

Table I (6)

Modulus of Elasticity

Pulp	Modulus of Elasticity p.s.i.	Freeness C.S.
Unbleached Kraft - Western	1,000,000	330
Bleached Kraft - Western	900,000	355
Bleached Sulfite - Western	850,000	280
Unbleached Sulfite - Western	590,000	350
Groundwood - Spruce	370,000	50
Groundwood - Spruce	270,000	100
News	330,000	170

The moment of inertia is an expression of the internal resisting moment that is set up within a body upon flexing. For a homogeneous sheet this may be expressed as:

$$I = \frac{h^3}{12}$$

where h is the sheet caliper in inches.

Combining this with the formula for stiffness gives:

$$\text{Stiffness} = \frac{E\,h^3}{12}$$

which shows the importance of thickness on stiffness in the homogeneous sheet. This has been shown to be valid in board when density is held constant.

So far, only homogeneous sheets have been considered. In the multiply structure the stiffness is equal to the sum of the stiffness values for each ply. This may be expressed as:

$$\text{Stiffness} = E_1 I_1 + E_2 I_2 + \cdots\cdots E_n I_n$$

where the subscript denotes the individual ply.

Figure I on page 8 shows two beams in cross section. Both beams are made up of three plies where each ply is made of either material X or material Y. Material X has a greater elastic modulus than does material Y. Figure IA shows these beams where the cross sectional area is proportional to the elastic modulus. Shown in this manner it can be seen that beam A will be stiffer than beam B.

Paperboard may be treated as an engineering material. When a piece of board is flexed, one surface is stretched while the other is compressed. Located between the two surfaces is a plane that retains its original length on flexing, the plane is neither stretched nor compressed. The

Figure I

Beam Comparison

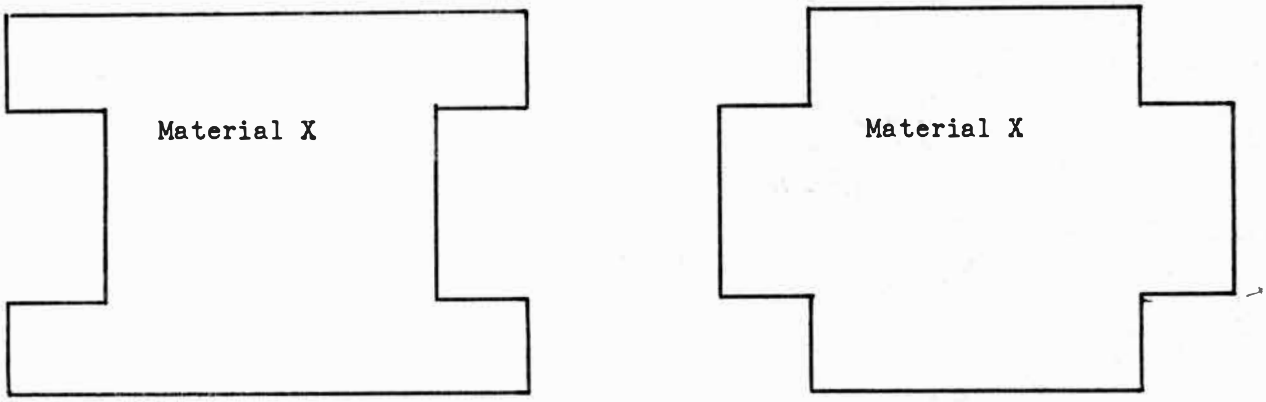
Beam A

Beam B

Material X has a greater elastic modulus than does material Y.

Figure IA

Beam Comparison



Beam A

Beam B

The cross sectional beam area is directly proportional to the elastic modulus.

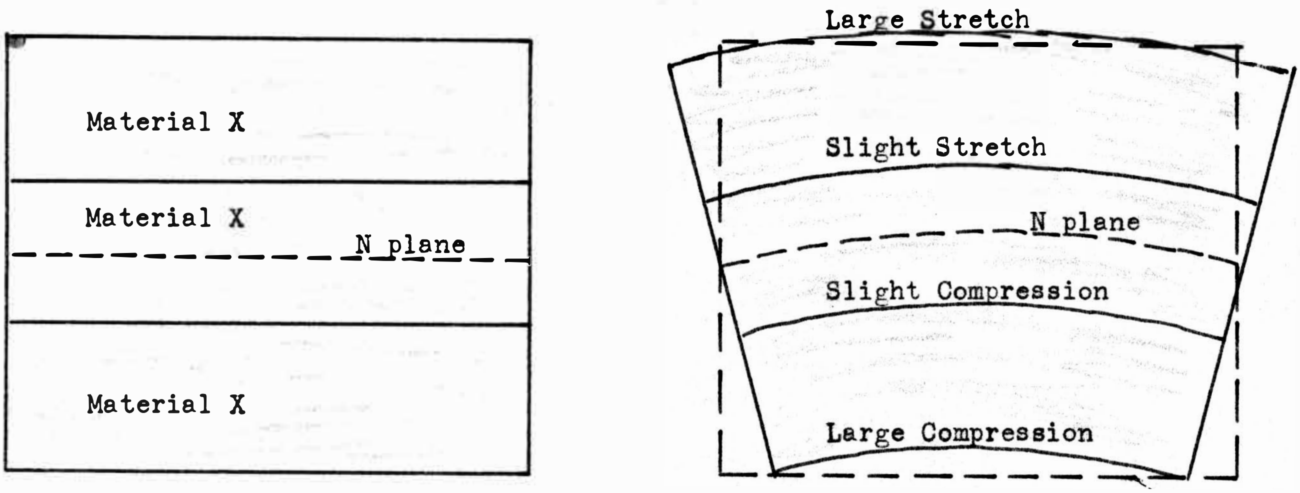
flexing of paperboard is shown in Figure II on page 10. Board A is symetrical in reference to the plane midway between the sheet surfaces. Therefore, the neutral plane is in the geometric sheet center.

Multiply board is seldom symetric to the plane midway between the sheet surfaces. When this is the case, the neutral plane will no longer be in the geometric center, but will be displaced toward the surface showing the higher modulus of elasticity. This is represented in Figure II A on page 10.

The areas of the sheet which exhibit the greatest distortion upon flexing are the areas of greatest moment of inertia values. It is seen in Figure II that these areas are the surfaces of the board. Therefore, due to geometric arrangement alone, the exterior plies of a multiply sheet will ply the major role in overall sheet stiffness. The work done here than, will show the effects of changing the ply arrangement, or in reality, changing the modulus of elasticy of the exterior plies of a multiply sheet.

Figure II

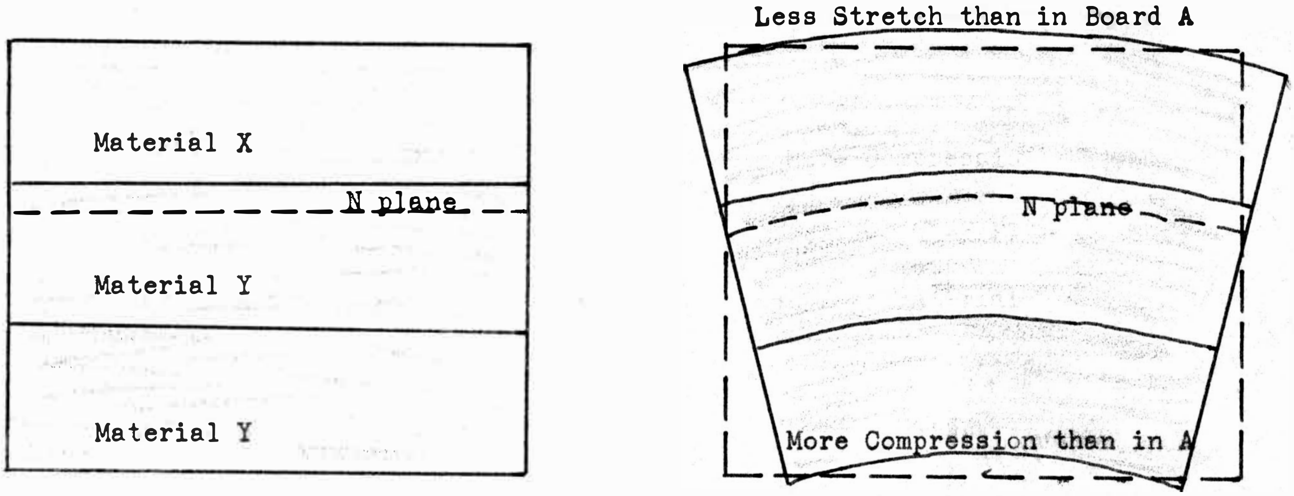
Flexing of Board



Board A   Board A when Flexed

All plies of material X. Neutral plane, N, in geometric center.

Figure IIA



Board B   Board B when Flexed

Material X has a greater elastic modulus than does material Y. Neutral plane not in geometric center.

The approach taken to the problem of ply arrangement effects on stiffness was that of forming handsheets with various ply arrangements, testing these sheets under standard conditions, and analyzing the results.

The first task was that of developing a method of producing multiply handsheets in the laboratory. The possibility of making a laminated structure was considered. When comparing laminated board with multiply board, differences are noted. The adhesive used in the lamination process is different from the material which makes up the sheet. In multiply board this is not the case for the material which cements the plies together is part of the sheet itself. In laminated board the strength of the bond is usually greater than the strength of the ply, whereas this is a rare case in multiply board. Therefore the method used for producing multiply handsheets had to involve a process other than lamination.

The method developed for making multiply sheets in the laboratory made use of the Noble and Wood handsheet apparatus. The drainage of water from a water-stock system was observed so the drain valve could be closed when the last bit of water was draining through the sheet. This was done when water would no longer glisten on the fiber mat surface. The removal of the sheet at this time, rather than after permitting air to pass through the sheet aided in the subsequent usage. On the other extreme, if too much water was present in the fiber mat, the mat was fluid-like and rather difficult to work with.

Upon removal of the fiber mat along with the forming wire from the sheet mold, it was placed wire side down on the press felt. A second sheet, to form the second ply, was formed in similar manner, than inverted, and placed on the first sheet. After wet pressing through the unloaded

wet press the top wire was carefully removed so any number of plies could be added, one at a time, in similar manner. Final wet pressing was accomplished by passing the sheet through the fully loaded wet press. This sequence of sheet forming is shown stepwise in Figure III on page 13.

Final wet pressing was followed by the removal of the forming wires, dring on the steam drum and testing later after conditioning.

Drainage direction should be noted here. When formed, the direction of drainage is toward the wire. In building up the sheet a ply at a time each ply after the first is inverted so the wire side is up. By this technique the direction of drainage is downward for the first ply, and upward for all other plies. This is a difference between lab-made and machine-made multiply board.

Handsheets have three plies were made from a bleached sulfite pulp and overissue news. Figure IV on page 14 shows the possible ply arrangements. It will be noted that there are two sets of mirror images; the SSN - NSS and the NNS - SNN pair. Stiffness measurements of these pairs should indicate differences in drainage direction, mentioned above, if this is an important factor.

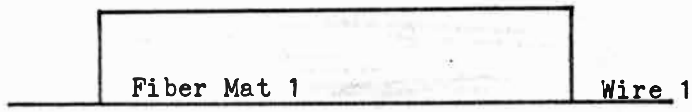
Duplicate sets of sheets in all eight possible ply configurations were made from the two pulps.

Upon testing these sheets with the Taber V-5 Stiffness Tester it was found that the average stiffness agreement between duplicate sheets was within 6.4 percent. Stiffness agreement between sheets in the mirror image pairs was within 6.0 percent. It was therefore felt that the differences in the mirror image pairs were due to experimental error, and not from drainage direction.

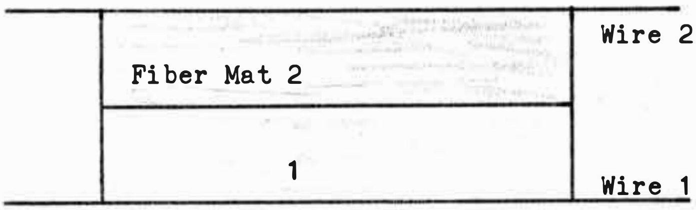
Figure III

Method of Handsheet Formation

Step I

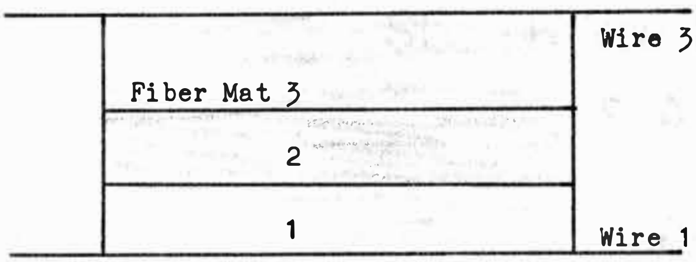


Step 2



Step 3 - Pass through unloaded wet press

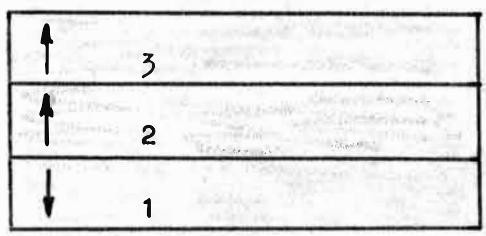
Step 4



Step 5 - Pass through unloaded wet press

Step 6 - Final press with full load

Finished Multiply Sheet



All plies of equal caliper.

Figure IV

Possible Ply Arrangements

Conditions:

Two components

Three plies.

Number of ply arrangements;

$$(2)^3 = 8$$

Ply arrangements:

A) Solid Sheets

1) NNN
2) SSS

B) Mixed Sheets

1) 2 S plies with 1 N ply

a) SNS
b) SSN ⟩ mirror images
c) NSS ⟩

2) 1 S ply with 2 N plies

a) NSN
b) NNS ⟩ mirror images
c) SNN ⟩

The results of the average stiffness values of the two sheets in each ply arrangement are shown in Figure V on page 16. As expected, the solid sulfite sheet had the greatest stiffness and the solid news the least. It is noted, however, that in the cases where both exterior plies are different from the center ply, the stiffness is of the same general magnitude as the corresponding solid sheet.

Identical work was carried out with the bleached sulfite at a higher freeness level. In general the results were very similar to the first set, and are shown in Figure VI on page 16. In both sets the value plotted is the average of ten taber tests; five test specimens from each of the duplicate sheets.

The same procedure was used to make five-ply sheets using the same two components, however, only freeness level of the bleached sulfite pulp was used, 250 CS. Each of the five plies contributed .004" to produce a .020" sheet.

Using two components to construct a five ply sheet there are two to the fifth power, or thirty two possible configurations. These thirty two possible arrangements can be classed as two solid sheets, eighteen mixed sheets, and twelve mirror images. Because of the insignificant differences found in the three-ply mirror image pairs in the area of stiffness, only one of the pair was made in the five ply set.

The area of interest for the five ply set concerns the stiffness of sheets having the identical sheet furnish, but different ply configurations. Figure VII on page 17 shows the effect of ply position upon stiffness of sheets having three bleached sulfite and two overissue news plies. Again, as in the case of the three ply sheets, the solid sulfite has the highest

Figure V

Stiffness vs Ply Arrangement

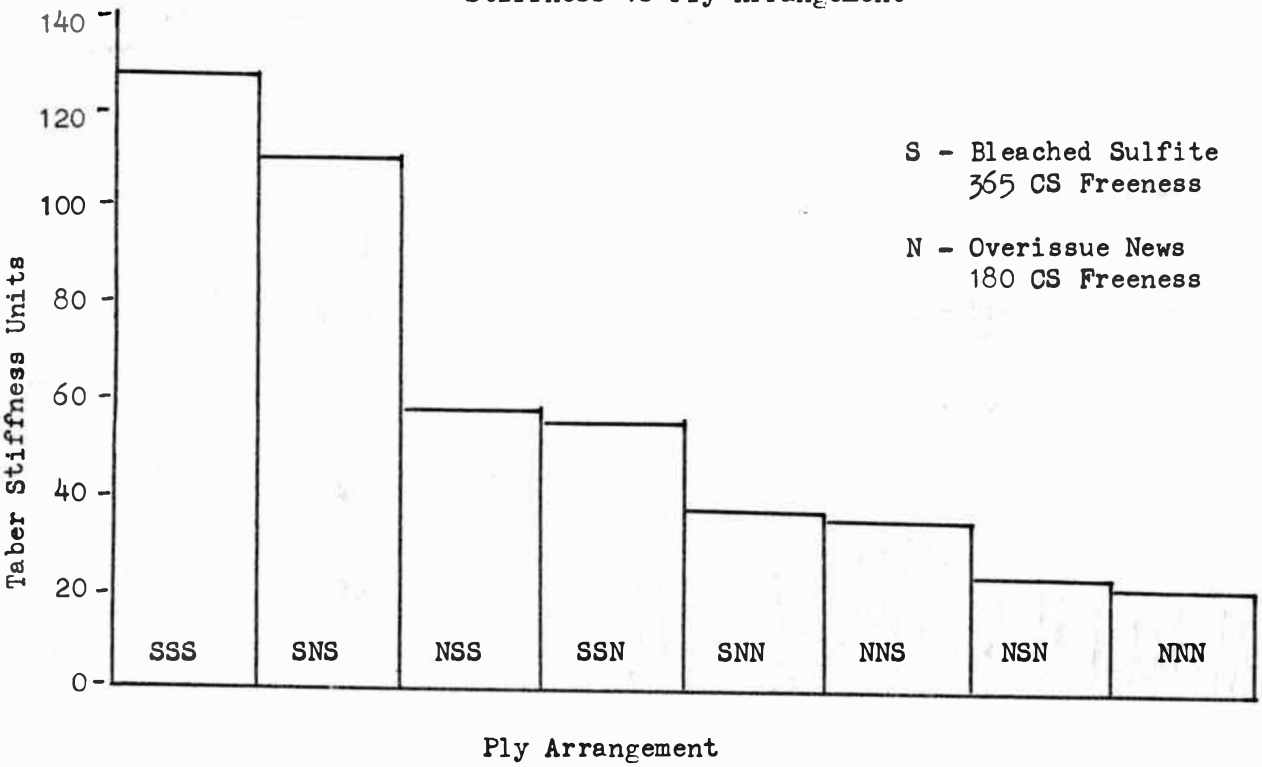


Figure VI

Stiffness vs Ply Arrangement

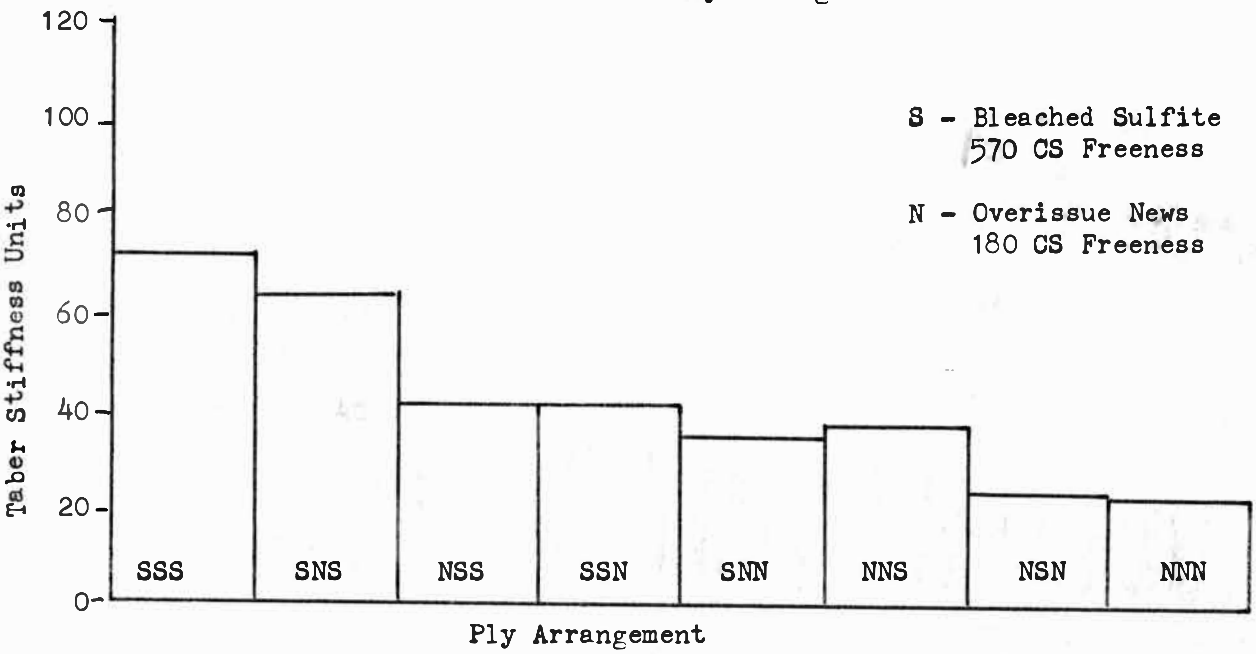


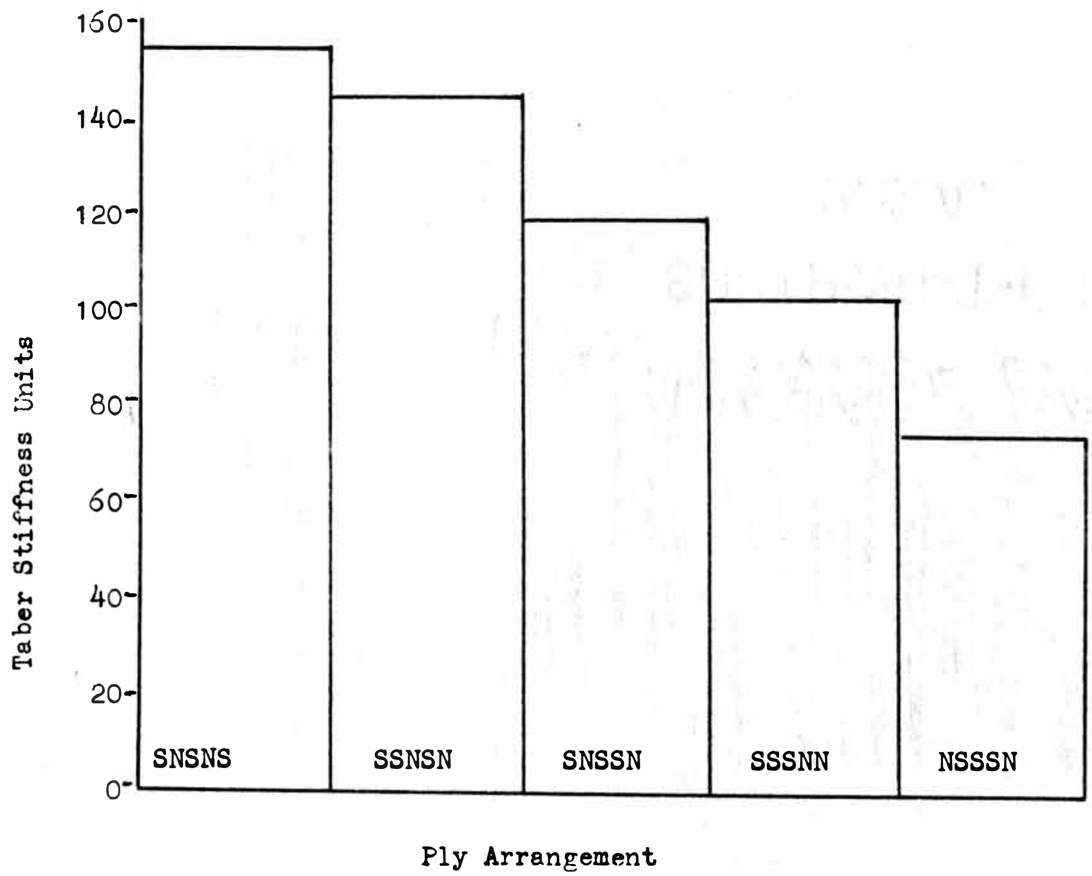
Figure VII

The Effect of Ply Position on Stiffness

Basic Furnish:

3 bleached sulfite plies

2 overissue news plies



stiffness. Placing the pulp having the higher elastic modulus, the bleached sulfite in this case, the maximum distance from the neutral plane results in higher stiffness. Conversely, when the news, having the lower modulus of elasticity, is placed in the liner positions, sheet stiffness decreases.

The last portion of this work delt with the investigation of the effects of adding a third pulp, a bleached kraft pulp, to the furnish. Again five ply handsheets were made as before. A portion of the stock in an individual ply was replaced with bleached kraft. By so doing the effects of upgrading could be determined.

A portion of this data where a single ply at a time of the basic NNNNS sheet was upgraded is shown in Figure VIII on page 19. It can be seen that upgrading the liner position plies results in the greater stiffness increases.

Figure VIII

The Effect of Upgrading on Stiffness

Basic Ply Arrangement:

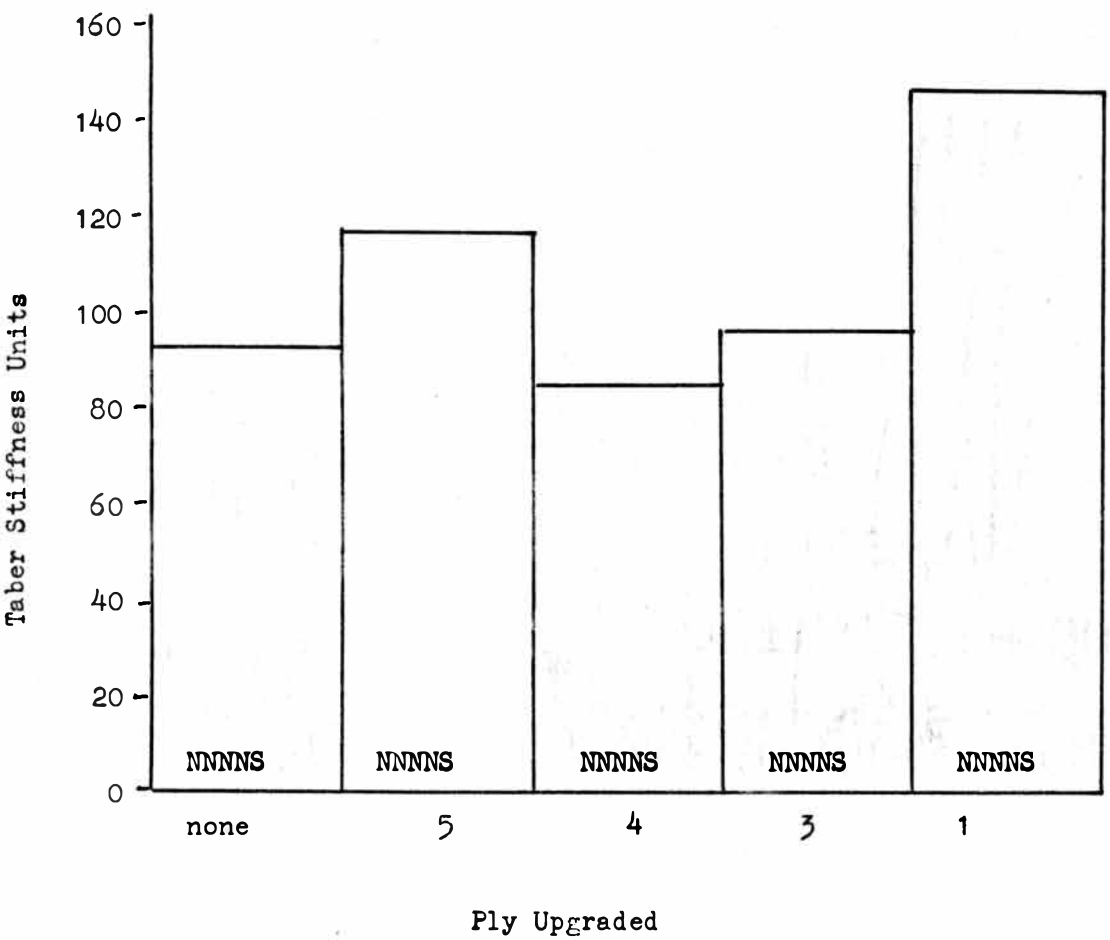
NNNNS
12345

Stock Added:

Bleached Kraft at 300 CS Freeness

Amount Added:

Bleached Kraft replaced 40% of original stock weight in ply.



CONCLUSIONS

From the foregoing the following conclusions were made:

1 The method employed for making multiply sheets in the laboratory gave accurate and reproducible results.

2 The modulus of elasticity and the moment of inertia of the liner plies are of primary importance in overall sheet stiffness.

3 The filler stock has the basic function of separating the liners causing the liner plies to have high moment of inertia values.

4 Upgrading to increase stiffness at constant caliper will have maximum results when done to the liner furnishes.

BIBLIOGRAPHY

1 Clark, James d'A; Determining the Rigidity, Stiffness, and Softness of Papers; Tech Assoc Papers 18, 234 (1935)

2 Casey, James P; Pulp and Paper, Vol 2; Properties of Paper and Converting; Interscience Publishers, New York, 1952

3 Carson, F.T. and Worthington, V; Stiffness of Paper; J. Res NBS 49, 385 (Dec 1952)

4 Sharman, C.F.; The Stiffness of Paper; Proc. Tech. Soc. Paper Makers Assoc of Gr. Brit. and Ireland 23, 231 (1942)

5 Peirce, F.T.; The 'Handle' of Cloth as a Measurable Quantity; J. Text Inst. 21, T377 (1930)

6 Luey, T,; Boxboard Stiffness, presented at National TAPPI, New York City, 1963.