MEMORANDUM

From: Wendell H. Smith

Project: Project 1102-3

In regard to the memorandum dated 9/30/68, Project Report dated 6/9/69 should be numbered Report No. 1102-3 and the report should be cancelled out as John Tagger said that he could not be a member writing a report.

WHS/dkb
INVESTIGATION OF METHODS FOR MICROSCOPIC EXAMINATION OF FIBERS
AND FIBER SYSTEMS RELATIVE TO REFINING AND FORMING

This work was initiated to determine if it was feasible to micro-
scopically observe a fibrous mat—both wet and dry—while the mat remained on
the forming screen and thereby determine the positions of the fibrous elements
in relation to each other and to the forming screen without disturbance. Many
workers have utilized microscopic methods for the determination of cell structure,
fiber identification, and the modification of fibrous elements during pulping
and refining, but few have extended these observations to include the effects
of pulping and refining in relationship to fibrous elements as they appear in a
formed fibrous mat. Part of the difficulty was caused by lack of stereo-
microscopes of suitable magnification ranges to permit such observations. The
recent acquisition of a StereoZoom 7 Microscope (Bausch & Lomb) with accessories
provided a stereomicroscope with magnification ranges of 10 - 210X, which opened
possibilities for viewing thin fibrous mats in the desired ranges of 50 - 150X.
Accessories included a camera adapter which can be utilized with the MP-3 Polaroid
unit for producing photos. To date, observations of dry fibrous mats on a screen
prove to be practical and potentially can yield interesting observations with
respect to mat formation character. Observations of wet fibers are more difficult
and less revealing; however, they are of potential interest if observations are
extended over the drying interval.
INITIAL DEVELOPMENT OF TECHNIQUES FOR MICROSCOPIC OBSERVATION

In order to observe mat character with both reflected and/or transmitted light, it was desired to form a sheet with a maximum thickness of three fibers. The forming device was a Buchner funnel (1-3/4 in. I.D.) fitted with a Plexiglas tube 10 inches long. Early trials produced nonuniform sheets. Difficulties were traced to formation of air bubbles and training the water below the forming screen. The following techniques provided sheets of the desired formation:

1. Place an O-ring into the Buchner funnel
2. Place the wetted forming screen on the O-ring (nylon of approximately 220 mesh was used as will be explained later)
3. Place an O-ring atop the forming mesh
4. Insert the Plexiglas tube
5. Add about 50 ml. water while holding the funnel drain closed
6. Drain the water to approximately 1 inch above the forming mesh and determine that no air pockets remain below the screen
7. Add pulp slurry, approximately 200 ml. stock at approximately 0.004% consistency
8. Allow to stand for one minute and gravity-drain; vacuum may be necessary to remove excess water below the forming mesh.
9. Remove the sheet and air dry, or observe wet as desired.

Three forming screens were tried: millipore filter paper; 250-mesh bronze; and white nylon fabric of approximately 220 mesh. The nylon mesh proved most suitable by reason of its translucence which permitted observations by transmitted and combination lighting as well as reflected light, whereby the lay of the fibers over the screen could be clearly discerned with the microscope. Because of these observations, black nylon fabric was purchased from Mary Lester's. Trials with
the black nylon proved that the desired increased contrast could be obtained between the forming mesh and the undyed fibers without losing the desired translucency under microscopic observation.

Neither the millipore filter or bronze screen proved satisfactory for viewing with transmitted or combination light.

It was also found that greatly improved contrast for undyed fibers could be achieved by the use of colored filters for microscopic viewing. Blue transmitted light (Wratten filter No. 45) combined with daylight reflected light and green (Wratten filter No. 58) transmitted light combined with orange (Wratten filter No. 22) reflected light proved to be especially suitable.

In addition to undyed fibers, fibers dyed with Chlorazol Black E were prepared. Chlorazol Black E is noted for its ability to dye fibrils, primary wall "skins", etc. as well as primary fibers. (Strelis, I., and Green, H. V. Pulp Paper Mag. Can. 62, No. C; T137-8, T160, Convention Issue, 1961.) Both hot and cold solutions were utilized; however, it is anticipated that cold solutions are less likely to modify the fiber. For cold dyeing, 15 cc. of approximately 0.05% consistency stock was added to 100 cc. of dye solution at a concentration of 10 g./l. After standing for 5 minutes, an additional 100 cc. of water was added and the sheet was formed. The dyeing provided very good contrast on the mats observed.

For this initial study, several pulps were observed:

1. A special experimental softwood pulp which was ball-milled (Project 2851), and observed at the following Canadian freenesses: 760 (as received); 300; 200; and 100.

2. A second experimental pulp from Project 2851 (80% hardwood furnish) was refined in the Valley beater to Canadian freenesses of: 650 (as received); 520; and 350.
Microscopic observations of both the dyed and undyed fibers over the range of 50-150X provided interesting views of the fiber character and relationships within the mat and to the forming screen. The various cells (fibers, vessel elements, fibrils, and fiber debris) were readily discerned. Combination reflected and transmitted lighting proved to be especially suitable, but both reflected and transmitted lighting—separately—have some value.

A number of photographs utilizing Polaroid PN-55 film were taken at the various lighting conditions, and the dyed mats formed from the ball-milled pulp were used.

Observations of wet fibrous mats proved to be difficult since sufficient contrast was not exhibited between fiber and water; however, some interesting observations were possible if the mat were observed throughout the drying stages.

SUMMARY

1. It is feasible to prepare uniform fibrous mats only a few fibers in thickness for microscopic observations.

2. Synthetic forming screens are especially suitable because their translucent nature permits transmitted and combination lighting observations of the fibers at screen intercepts as well as interstices.

3. The StereoZoom 7 microscope will permit stereo-observations of dried fibers in position at magnifications in the range of 50-150X so that the various cells can be identified and structural implications can be determined.

4. Combination reflected and transmitted lighting often provides the best stereo view of the fibers, but comparison observations under all forms of lighting are useful.

5. Filter combinations can be utilized to enhance the contrast for viewing undyed fibers.

6. Fibers dyed with Chlorazol Black E provide good contrast for fibrils and fiber debris as well as the primary fibers.

7. Observations can be recorded photographically.
SUGGESTIONS FOR FUTURE WORK

1. Effect the following improvements of the techniques described above toward establishing routine and speedier procedures:
   a. Modification of the forming mechanism;
   b. Evaluation of the use of color films and the use for filters in the photographic step;
   c. Determination and close control of ideal fiber mat weights for microscopic examination;
   d. Potential use of dyed nylon screens to obtain greater contrast between the forming mesh and the formed mat;
   e. Potential use of dyes other than Chlorazol Black E, and possibly more effective dyeing techniques.

2. Microscopic study of the character of fibrous mat formation for several pulps refined to various levels of beating (possibly beaten with various refining mechanisms) to determine potential changes in mat formation character including preferred positions of various cells and cell fragments within the mat--viz., fibers, vessel elements, fibrils, fiber debris, etc.

3. Correlation of the microscopic study (No. 2 above) with other tests such as: wet mat compressibility; filtration resistance; specific surface; water retention values; and physical tests of normal handsheets in an attempt to explain the character of mat formation as it may be exemplified by these tests.

4. Study of changes in mat formation upon addition of wet-end additives.

5. Study of dyes and dyeing relative to cell structure, final sheet color, etc.

6. If visual observations of a formed mat were recorded and supplemental photographs were readily available, it would seem that many areas of applied interest--as well as fundamental aspects--could be enriched.
EFFECT OF SHRINKAGE ON HANDSHEET PROPERTIES

SUMMARY

A very preliminary experimental investigation was performed to determine the effects produced when handsheets were dried under different degrees of restraint. It was found that folding endurance, bursting strength, stretch, and toughness characteristics were improved, and tensile strength properties were decreased, when handsheets were allowed to shrink during the drying operations. A theory was advanced to explain some of these effects and it was suggested that further work be done to verify it.

EXPERIMENTAL PROCEDURES

The following procedures were involved in the experimental work:

(1) A bleached aspen kraft pulp was refined in a 1.5-lb. Valley beater and samples were removed at three different refining intervals.

(2) A series of TAPPI standard weight handsheets was formed from each of the samples. These sheets were left on the couching blotters, covered with fresh blotters, placed under a weighted felt, and dried on a drum drier.

(3) A second series of handsheets was formed in the same manner. These sheets were removed from the couching blotters, laid on fresh blotters,
covered with fresh blotters, placed under a weighted felt, and dried on a drum drier. (In this case, the substitution of a fresh blotter for the couching blotter resulted in less adhesion between the blotters and the wet handsheets. Consequently, the sheets were free to shrink to a greater degree during the drying operation. These sheets were puckered around the edges, but flat and smooth in the areas generally utilized for handsheet testing.)

(4) The dried handsheets were conditioned and subsequently tested.

RESULTS

The results of this preliminary investigation have been summarized in Table I. On the basis of these results, it would appear that:

(1) The two different types of handsheet drying techniques resulted in different handsheet shrinkage properties.

(2) Increasing the degree of shrinkage in handsheets prepared from a given pulp produced the following effects:

(a) Basis weight tended to increase.
(b) Caliper tended to decrease.
(c) Apparent density tended to increase.
(d) Bursting strength tended to increase.
(e) Tearing strength tended to remain essentially the same.
(f) Tensile strength tended to decrease.
(g) Stretch tended to increase.
(h) Work to rupture tended to increase.
(i) Folding endurance tended to increase.
(j) Formation characteristics tended to decrease.

(3) These results appeared to be compatible with results reported in Project 1708, Project Reports 10 and 12—i.e., unrestrained drying of cotton linters handsheets resulted in improved folding endurance properties and decreased tensile strength properties.

CONCLUSIONS

The results of this exploratory study would indicate that unrestrained drying techniques might prove beneficial for papers in which high folding endurance properties, high bursting strength properties, good stretch properties, and high levels of toughness, are desired. However, such drying techniques would apparently prove detrimental in cases where maximum tensile strengths are required.
FUTURE WORK

Future work regarding the effects of unrestrained drying might consist of essentially the following two phases:

1. An investigation similar to the present work, with the exception that several series of handsheets would be prepared over a range of basis weights. This would allow direct comparisons under equivalent basis weight conditions. Consequently, possible effects and complications resulting from basis weight changes during the various drying operations would be eliminated, and a better comparison and analysis could be made of the true effects of handsheet shrinkage.

2. An investigation in which the extent of handsheet shrinkage would be increased to levels higher than those investigated in the present work. However, it might be difficult to attain higher shrinkage levels and still maintain a flat, smooth-surfaced handsheet for testing purposes.

In the event that future work is performed on this project, it would appear desirable to include a number of additional tests such as opacity measurements, zero-span tensile strength measurements, etc.

At the present time, a series of handsheets are being treated by the "Clupak" treatment and it would be interesting to check these results with the results in this report. Consequently, no immediate work has been contemplated until those results become available.
DISCUSSION

It would be interesting to speculate on possible theories which may account for the results noted in this work. One such theory might be developed with the aid of Figures 1 and 2.

Figure 1 represents a very simplified theoretical sketch of portions of two adjacent fibers in a handsheet dried under restraint--i.e., dried according to usual laboratory techniques. Figure 2, represents a theoretical sketch of the same portions of the same adjacent fibers in a handsheet dried under conditions designed to promote shrinkage--i.e., dried in an unrestrained manner.

In both figures, point A denotes an area of highly concentrated bonding and the dark portions along the body of the fibers represent fibrils. Referring to Figure 1, it may be seen that the fiber bodies are relatively straight and that many of the fibrils are bonded to the parent fibers. In Figure 2, however, it may be seen that more of the fibrils are bridged between the fiber bodies and the fiber bodies are kinked to a greater extent. Also, although it is not shown in the figure, the fiber bodies may be more twisted than in the case represented in Figure 1.

The reason for the differences represented in Figures 1 and 2 might be explained as follows:

(1) In the case of the restrained drying (Figure 1), the fibers are held relatively far apart. Consequently there is less opportunity for fibrillar bridging and most of the interfiber bonding in the handsheet is concentrated at areas where there is good contact between the fibers (point A).

(2) In the case of unrestrained drying (Figure 2), the fibers are
freer to move during the drying operation and surface tension forces, etc.,
can bring the fiber bodies closer together. As a result, more of the fibrils
tend to bond to adjacent fibrils and fibers, and more fibrillar bridges
develop. Forces developed during the formation of these fibrillar bridges
tend to kink and twist the fibers in the manner represented in Figure 2.
Again, most of the interfiber bonding, and the strongest bonding, in the
handsheet is concentrated at areas where there is very good contact between
the fibers (point A). In this case, however, the stress and strains set up
by the formation of more fibrillar bridges, and subsequent twisting of the
fiber bodies, may, to some extent, tend to reduce the effectiveness and the
extent of the highly concentrated bonding area developed at Point A.

Although this theoretical picture has been developed with regard
to the restrained and unrestrained drying of handsheets, it may be seen
that much the same effects could be developed when the bonding capacity and
fibrillation characteristics of a pulp were increased by means of increased
refining, etc.—i.e., as refining proceeded, the fibers in standard handsheets
would tend to progressively exhibit more of the characteristics represented
in Figure 2.

On the basis of this theoretical picture, it would be possible to
analyze the experimental results in the following manner:

(1) The higher basis weight, lower caliper, and higher apparent
density characteristics in the sheets unrestrained during drying would result
from the greater freedom of movement allowed the fibers—i.e., the fibers
were free to be drawn closer together during the drying operation.
(2) The higher stretch properties would result from the increased degree of fibrillar bridging and the increased degree of fiber kinking and twisting associated with this bridging--i.e., when the handsheets are subjected to tensile loads, the fibrillar bridges will tend to stretch and break. Also, the kinked fibers will tend to stretch and straighten before the full force becomes concentrated on the strongly bonded areas represented by Point A in the figures.

(3) The increased work required to rupture the sheet would result from essentially the same factors mentioned in (2), above--i.e., additional work would be required to stretch and break the fibrillar bridges, and stretch and straighten the fiber bodies, before the load could cause failure by concentrating on the more strongly bonded portions of the fibers.

(4) Bursting strength, of course, is influenced by both tensile strength and stretch characteristics. Thus, the same factors mentioned in (2) above would tend to enhance bursting strength properties.

(5) Folding endurance characteristics would also tend to be enhanced by the factors previously discussed--i.e., the fibrillar bridging and associated effects would tend to produce a network throughout the sheet which would be elastic and tend to absorb the forces developed during folding.

(6) The decrease in tensile strength would be due to the fact that the stress and strains developed by fibrillar bridging twist the fibers and tend to disrupt the bonding in areas of high bonding concentrations. It is, of course, these areas of highly concentrated bonding which will determine the ultimate tensile strength of the paper--i.e., the fibrillar bridges will break prior to the application of the ultimate tensile load.

(It should be noted that fiber strength would also govern the strength of...
(7) In the case of the experimental work, tearing strength remained essentially the same because of certain compensating factors. This may be seen as follows:

(a) A major contribution to tearing strength is the work required to pull the fibers from the sheet.

(b) Fibrillar bridging and the resulting stresses and strains will reduce the extent and the effectiveness of bonds developed in the areas of highly concentrated bonding. Hence, less work would be required to pull the fibers from the sheet, and tearing strength will tend to decrease.

(c) Fibrillar bridging would in itself tend to require more work to pull the fibers from the sheet. Hence, tearing strength will tend to increase.

(d) In the experimental work, the balance between the factors discussed in (b) and (c) above were of such nature that the tearing strength remained essentially the same.

(8) The slight decrease in formation properties may have been due to the twisting and disruption of fibers associated with greater degrees of fibrillar bridging.

It is interesting to note that these same theories would tend to explain other phenomena associated with the strengths of paper. The following would tend to serve as examples:

(1) It has been noted that fiber flexibility appears to increase folding endurance. A reference to Figure 2 indicates that the ability for
fibrillar bridges to form, and the ease with which fiber bodies can be kinked would be related to fiber flexibility.

(2) It has been noted that at the higher refining levels such properties as folding endurance and stretch can be greatly increased without much effect on tensile strength. Increased fibrillar bridging and its associated effects might account for such results.

(3) It has been noted that the addition of fines has a much greater effect on folding endurance improvements than on tensile strength. In this case, the fines may act in the same manner as fibrillar bridges.

(4) It has been noted that the addition of fines to low refined pulps improves stretch, whereas the addition of fines to highly refined pulps sometimes tends to reduce stretch. In both cases the fines tend to act as fibrillar bridges and improve stretch. In the case of the highly refined pulps, however, the addition of fines reduces the already shorter average fiber length and it becomes more difficult for short fibers to become kinked in the manner represented in Figure 2. Consequently, stretch tends to decrease.

(5) The theory could explain why tensile strength and folding endurance correlations differ between different pulps—i.e., the extent of fibrillar bridging, etc., may vary in the pulps. The theory would also be compatible with the fact that stretch and folding endurance correlations may vary between different pulps—i.e., in the case of stretch, fiber length would be of considerable importance (see [5] above); however, an elastic network of fibrils, beneficial for folding endurance, could still be produced in the handsheet with relatively short fibers. Thus, stretch and fold correlations could vary, if it were assumed that the ultimate stretch of the paper were not necessarily utilized in folding.
(6) The theory would be compatible with the fact that at the higher refining levels, an increase in specific surface can produce tremendous increases in folding values without affecting the tensile strength values.

Numerous other examples might be cited; however, little additional information would be gained by such efforts. Instead, it is suggested that the theory be considered from a number of angles, and that an extensive discussion and exchange of viewpoints be contemplated in the near future.

The complete experimental verification of the theory would perhaps be involved and tedious. However, certain rather simple experiments and an application of this viewpoint to stress-strain diagrams and balances between strength properties may greatly aid in determining the feasibility of the theory. One such experiment might involve drying closely spaced fibers under a microscope and noting whether fibrillar bridging and bonding can result.

mhw/jh
Figure 1

Fibers in a Handsheet Dried Under Restraint
Figure 2

Fibers in a Handsheet Dried Without Restraint
### TABLE I

**EFFECT OF SHRINKAGE ON HANDSHEET PROPERTIES**

<table>
<thead>
<tr>
<th></th>
<th>Handsheets Dried on Drum Drier According to Usual Techniques</th>
<th>Handsheets Dried on Drum Drier Under Conditions Designed to Promote Shrinkage</th>
</tr>
</thead>
<tbody>
<tr>
<td>Refining time, min.</td>
<td>0</td>
<td>30</td>
</tr>
<tr>
<td>Schopper-Riegler freeness, ml.</td>
<td>835</td>
<td>560</td>
</tr>
<tr>
<td>Thwing formation, units</td>
<td>111</td>
<td>80.6</td>
</tr>
<tr>
<td>Basis weight (25x 40--500), lb.</td>
<td>46.4</td>
<td>46.3</td>
</tr>
<tr>
<td>Caliper, mils</td>
<td>5.7</td>
<td>3.6</td>
</tr>
<tr>
<td>Apparent density</td>
<td>8.1</td>
<td>12.9</td>
</tr>
<tr>
<td>Bursting strength, pt./100 lb.</td>
<td>25</td>
<td>81</td>
</tr>
<tr>
<td>Tear factor</td>
<td>0.58</td>
<td>0.60</td>
</tr>
<tr>
<td>Tensile strength(^1), lb./in./45-lb. sheet</td>
<td>10.0</td>
<td>25.7</td>
</tr>
<tr>
<td>Stretch, %</td>
<td>1.6</td>
<td>2.4</td>
</tr>
<tr>
<td>M.I.T. folding endurance, double folds</td>
<td>2</td>
<td>197</td>
</tr>
<tr>
<td>Work to rupture (based on 15 mm.-width strips), in.-lb.</td>
<td>0.28</td>
<td>1.06</td>
</tr>
<tr>
<td>Handsheet shrinkage(^3), %</td>
<td>0.98</td>
<td>1.33</td>
</tr>
</tbody>
</table>

\(^1\) Tensile strength measurements were made on 4-in. by 15-mm. test strips.
\(^2\) Work to rupture determined by making planimeter readings on the stress-strain diagrams.
\(^3\) Handsheet shrinkage measurements were performed according to Institute Method 406.
JOKRO MILL STUDY

INTRODUCTION

A short experiment was carried out on the Jokro mill to give an indication of its refining action as compared to the Valley beater and the ball mill.

EXPERIMENTAL

The raw material used in this study was a bleached sulfite pulp which was similar to the pulp used by Project 1513 in the Valley beater study.

The stock was refined in the Jokro mill according to Pulping Group Procedure 58 with all six refining chambers used for each interval. Handsheets were prepared from each interval according to Institute Method 411.

The physical tests employed in this study will be found in Table I. The experimental data obtained in this study are presented in Tables II and III. Valley beater and ball mill data used here were taken from Project 1513, Progress Reports 16 and 21.
TABLE I

PHYSICAL TESTS

<table>
<thead>
<tr>
<th>Test</th>
<th>Institute Method</th>
</tr>
</thead>
<tbody>
<tr>
<td>Conditioning</td>
<td>503</td>
</tr>
<tr>
<td>Basis weight</td>
<td>504</td>
</tr>
<tr>
<td>Caliper</td>
<td>508</td>
</tr>
<tr>
<td>Apparent density</td>
<td>508</td>
</tr>
<tr>
<td>Tearing strength</td>
<td>512</td>
</tr>
<tr>
<td>Tensile strength</td>
<td>511</td>
</tr>
<tr>
<td>Filtration resistance and components</td>
<td></td>
</tr>
<tr>
<td>Zero-span tensile strength</td>
<td>Project 1513, Progress Report 13 Schopper tester, I.P.C. jaws</td>
</tr>
<tr>
<td>Relative bonded area (RBA)</td>
<td>Project 1513. Progress Report 16</td>
</tr>
</tbody>
</table>
### TABLE II

PHYSICAL PROPERTIES

<table>
<thead>
<tr>
<th>Refining Time, min.</th>
<th>5</th>
<th>10</th>
<th>15</th>
<th>25</th>
</tr>
</thead>
<tbody>
<tr>
<td>Basis weight, (25 x 40/500) lb.</td>
<td>46.4</td>
<td>46.4</td>
<td>46.1</td>
<td>46.4</td>
</tr>
<tr>
<td>Caliper, mils</td>
<td>3.4</td>
<td>3.2</td>
<td>3.1</td>
<td>2.9</td>
</tr>
<tr>
<td>Apparent density, g./cc.</td>
<td>13.6</td>
<td>14.5</td>
<td>14.9</td>
<td>16.0</td>
</tr>
<tr>
<td>Tear factor, g./g.</td>
<td>1.19</td>
<td>0.91</td>
<td>0.80</td>
<td>0.73</td>
</tr>
<tr>
<td>Tensile strength, lb./in. (corrected to 45 lb. sheet)</td>
<td>16.2</td>
<td>21.4</td>
<td>21.8</td>
<td>23.7</td>
</tr>
<tr>
<td>Zero-span tensile strength, lb./in. (corrected to 45 lb. sheet)</td>
<td>37.6</td>
<td>37.1</td>
<td>38.8</td>
<td>40.7</td>
</tr>
<tr>
<td>Relative bonded area, %</td>
<td>18.0</td>
<td>29.8</td>
<td>31.1</td>
<td>39.0</td>
</tr>
</tbody>
</table>

### TABLE III

FILTRATION RESISTANCE AND COMPONENTS

<table>
<thead>
<tr>
<th>Refining Time, min.</th>
<th>5</th>
<th>10</th>
<th>15</th>
<th>25</th>
</tr>
</thead>
<tbody>
<tr>
<td>$R \times 10^{-8}$, cm./g. (at 10 cm. water pressure drop)</td>
<td>0.40</td>
<td>0.57</td>
<td>0.84</td>
<td>1.75</td>
</tr>
<tr>
<td>Specific surface, cm.$^2$/g.</td>
<td>10,900</td>
<td>13,400</td>
<td>16,200</td>
<td>22,800</td>
</tr>
<tr>
<td>Specific volume, cm.$^3$/g.</td>
<td>1.52</td>
<td>1.71</td>
<td>1.90</td>
<td>2.30</td>
</tr>
</tbody>
</table>
DISCUSSION

Tear, tensile, and zero-span tensile were run on handsheets prepared at each interval from whole stock. Figures 1 through 6 show the results of these tests as a function of refining time and filtration resistance. Data from the Project 1513 Valley beater study is also included for comparison purposes.

The tensile vs. time curve (Figure 1) for the Jokro refined pulp shows the tensile increasing quite rapidly and approaching the maximum after about 25 minutes of refining while the Valley beater tensile develops slower and is still increasing after 35 minutes of beating. The tear vs. time curve (Figure 2) shows the Jokro tear decreasing very rapidly early in the refining process and leveling off after 25 minutes of refining. The zero-span tensile vs. time plot (Figure 3) shows the same type of zero-span tensile development for both machines.

The filtration resistance vs. time curves (Figure 4) for both refining machines are identical in this instance showing that filtration resistance is developed at about the same rate for each. The tear and tensile curves as functions of filtration resistance show the same type of development of the two properties and the same relationship between the Jokro mill and the beater as was seen in the plots as functions of refining time.

Handsheet properties were also compared at given levels of relative bonded area (RBA). Along with this comparison, RBA data from both refining machines were plotted as a function of refining time (Fig. 7). The tensile vs. RBA plot (Figure 8) shows the Jokro tensile somewhat higher at low levels
of RBA and tending to reach a maximum at a lower level of RBA than the beater tensile. The tear vs. RBA curves for both machines tend to parallel each other with the Jokro tear being lower at a given RBA.

Specific surface and specific volume were measured and the results for both refining machines plotted (Figures 10 and 11). Specific surface develops at about the same rate in both cases. The specific volume curves, however, are much different. The Jokro mill pulp specific volume increases very slowly with the curve presenting a slight concavity while the beater specific volume increases rapidly and gives much higher numbers at given refining times in the range studied.

Tensile was plotted as a function of specific volume for three different refining machines; the Jokro mill, Valley beater, and the ball mill (Figure 12). The ball mill data were taken from an earlier Project 1513 report in which essentially the same pulp was used. The data fell on three distinctly different curves which were straight lines in the case of the beater and ball mill. The Jokro mill data was represented as a straight line because of the previous data. At a given specific volume the three machines can be rated in respect to tensile strength development in this order; Valley beater (least), ball mill, Jokro mill.

Tensile vs. apparent density (Figure 13) and tear vs. tensile (Figure 14) were plotted and the curves were observed to be of the same general pattern as those from the beater study.

jb/mrb
FIGURE 1

TENSILE AS A FUNCTION OF REFINING TIME
Figure 7

Test Period

Jima

Bester

Enfiling time, min.
FIGURE 6
TENSILE AS A FUNCTION OF FILTRATION RESISTANCE

Tensile, lb./in.

0 1 1.5 2

H x 10^-6 cm^2/g.
FIGURE 7

RELATIVE BONDED AREA AS A FUNCTION OF REFINING TIME
FIGURE 5
TENSILE AS A FUNCTION OF RELATIVE BONDED AREA
FIGURE 9

Yield as a Function of Relative Bonded Area

Yield Factor

20 25 30 35 40
RMA, $
FIGURE 19

SPECIFIC SURFACE AS A FUNCTION OF REFINING TIME

Specific surface, cm²/g

0 5 10 15 20 25

Refining time, min.
FIGURE 11
TENSILE AS A FUNCTION OF SPECIFIC VOLUME

Specific volume, cm$^3$/g