SLIDE BOOKLET

to the

PAPER PHYSICS

PROJECT ADVISORY COMMITTEE

OCTOBER 28, 1998
INSTITUTE OF PAPER SCIENCE AND TECHNOLOGY

Atlanta, Georgia

SLIDE MATERIALS

PAPER PHYSICS

OCTOBER 28, 1998
# PAPER PHYSICS
## PROJECT ADVISORY COMMITTEE MEETING

**October 28, 1998**

Institute of Paper Science and Technology
Atlanta, Georgia

### PROGRAM REVIEW AGENDA

**Room 173**

<table>
<thead>
<tr>
<th>Time</th>
<th>Topic</th>
<th>Presenter</th>
</tr>
</thead>
<tbody>
<tr>
<td>1:00 p.m. – 1:10 p.m.</td>
<td>Opening Remarks and Antitrust Statement</td>
<td>John Waterhouse &amp; Doeung Choi</td>
</tr>
<tr>
<td>1:10 p.m. – 1:20 p.m.</td>
<td>Welcome from Vice President of Research</td>
<td>Gary Baum</td>
</tr>
<tr>
<td>1:20 p.m. – 1:50 p.m.</td>
<td>Project F007 On-line Measurement of Paper Properties</td>
<td>Mac Hall</td>
</tr>
<tr>
<td>1:50 p.m. – 2:20 p.m.</td>
<td>Project F008 Fundamentals of Acoustic Radiation</td>
<td>Pierre Brodeur</td>
</tr>
<tr>
<td>2:20 p.m. – 2:50 p.m.</td>
<td>Project F031 Paper Stiffness Properties VS Papermaking Variables</td>
<td>Pierre Brodeur</td>
</tr>
<tr>
<td>2:50 p.m. – 3:20 p.m.</td>
<td>Project F020 Fundamentals of Dimensional Stability</td>
<td>Doug Coffin</td>
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<td>3:20 p.m. – 3:30 p.m.</td>
<td>Break</td>
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<tr>
<td>3:30 p.m. – 4:00 p.m.</td>
<td>Project F026 Fundamentals of Accelerated Creep</td>
<td>Chuck Habeger</td>
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<tr>
<td>4:00 p.m. – 4:30 p.m.</td>
<td>Project F023 Micromechanics of Fiber Networks</td>
<td>Martin Ostaja</td>
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<tr>
<td>4:30 p.m. – 5:00 p.m.</td>
<td>Project F024 Fundamentals of Refining and Fiber Properties</td>
<td>John Waterhouse</td>
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<tr>
<td>5:00 p.m. – 5:30 p.m.</td>
<td>Project F025 Fundamentals of Interfiber Bonding</td>
<td>Hiroki Nanko</td>
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</tbody>
</table>

*Dinner will be served at 6:00 p.m. in the Paper Plate Café*

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PAPER PHYSICS
PROJECT ADVISORY COMMITTEE MEETING

October 29, 1998

Institute of Paper Science and Technology
Atlanta, Georgia

COMMITTEE DISCUSSIONS AGENDA

SEMINAR ROOM

8:00 a.m.-8:15 a.m.
- Antitrust Statement
- New Members
- Review of RAC -- PAC Meeting & Paper Physics Strategic Plan
- Review of Agenda

8:15 a.m.-9:30 a.m. Subcommittee Discussions
Conference Room 272
- Project F007 On-line Measurement of Paper Properties
- Project F008 Acoustic Radiation Pressure
- Project F031 Paper Stiffness Properties VS Papermaking Variables

Conference Room 372
- Project F020 Dimensional Stability
- Project F026 Accelerated Creep

Conference Room 472
- Project F023 Micromechanics of Fiber Networks
- Project F024 Fiber Properties
- Project F025 Bonding

9:30 a.m. Full Committee Discussion

11:00 a.m. New Projects – Dr. Doeung Choi
Other Business - ROCIT

12:00 p.m. Adjourn

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ON-LINE MEASUREMENT OF PAPER PROPERTIES

Project F007

Mac Hall
Ted Jackson
Andy Brown
Research Line/Roadmap

12. Sensors and Process Control
   • Develop on-line sensors
   • Develop algorithms/models relating material and manufacturing variables to process and product

10. Energy Performance
   • Reduce energy consumption
Ultrasound Velocity Provides Nondestructive Measure of Elastic Stiffness

\[(\text{Ultrasound Velocity})^2 = \frac{\text{Elastic Stiffness}}{\text{Sheet Density}}\]

= Specific Elastic Stiffness
Ring Crush = \( a + b \times E_{xt} + c \times E_{yt} + d \times E_{zt} \)

\[
= a + b \times (V_{MD})^2 \times BW
+ c \times (V_{CD})^2 \times BW
+ d \times (V_{ZD})^2 \times BW
\]

Similarly for STFI:

\[
STFI = a + b \times E_{xt} + c \times E_{yt} + d \times E_{zt}
\]
Reel 35 (35# Liner) - Average of 3, 2" CD Intervals

\[ \text{Ext} = V_{md}^2 \times BW \]
\[ \text{Eyt} = V_{cd}^2 \times BW \]
\[ \text{Ezt} = V_{zd}^2 \times BW \]

Calculated CD RC = 0.020\text{Ext} + 0.050\text{Eyt} + 0.542\text{Ezt} + -32.255

\[ R^2 = 0.826 \]
Project Participants with DOE-OIT Cooperative Agreement DE-FC02-95CE41156

- Institute of Paper Science & Technology
  - Atlanta, Georgia
- ABB Industrial Systems Inc
  - Columbus, Ohio
- Georgia-Pacific Corporation
  - Host Mill, Cedar Springs, Georgia
- Herty Foundation
  - Savannah, Georgia
Geometric mean of the longitudinal stiffnesses is proportional to the shear stiffness:

\[ G = \rho (V_{SH})^2 \equiv \left[ (E_{MD})(E_{CD}) \right]^{1/2} \]

\[ \frac{2}{\left[1 + (v_{MD}v_{CD})^{1/2}\right]} \]

where

\[ (v_{MD}v_{CD})^{1/2} \approx 0.293 \]

\[ E_{MD} = \rho (V_{MD})^2 (1 - v_{MD}v_{CD}) \]

\[ E_{CD} = \rho (V_{CD})^2 (1 - v_{MD}v_{CD}) \]

\[ \therefore (V_{SH})^2 \approx 0.354 (V_{MD})(V_{CD}) \]

or \[ V_{MD} \approx 2.8 \frac{(V_{SH})^2}{V_{CD}} \]
$K = (MD \text{ Vel}) \times (CD \text{ Vel}) / (\text{Shear Vel})^2$
Process Variables Which Affect ZD Web Properties

- Furnish
- Refining
- Wet Pressing
- Wet Straining
- Calendering
ZD “Advanced Engineering Prototype”

1. ZD system installed and tested on web handler in ABB Lab in Columbus, OH, July 6-9, 1998.

2. Installed on PM#1 at G-P during outage, July 28. Had electrical connection problems via cabling in scanner. After adjusting timing of steering reversal at edges, no wrinkles. Transducer came loose in upper tire, wore groove inside of tire. Brought system back to IPST.

4. Returned modules to the Mill September 8-11, and collected data for a total of 30 hours and 480 miles.

5. Worked on system at Mill during September 16 outage, still low receiver signal-to-noise.

6. Took additional data September 22-23. Tried to improve receiver signal by increasing pressure in tire. Tire cracked. Transducer caps blistered. Returned modules to IPST.

7. Adding air cooling of tires and will install coax in scanner for receiver signal in December.
Transmitting Ultrasonic Transducer

Tire Specimen

P_e3 P_e4

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ZD Velocity = $V_{zd} = \text{Caliper}/t_{zd}$

Acoustic Impedance = $Z = \rho V_{zd} = BW/t_{zd}$
# Georgia Pacific Cedar Springs Operations
No. 1 Paper Machine PI Tags

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<tr>
<th>PI Tag</th>
<th>Descriptor</th>
<th>Typical Value</th>
<th>Units</th>
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<td>Moisture Scan Average</td>
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<td>COND WT</td>
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<td>FPM</td>
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<td>Active Headbox Head</td>
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<td>SEC</td>
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</table>
FactNet 4.0

Solutions
FOR THE PULP AND PAPER INDUSTRY

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Define preliminary specifications – Nov 98

Final specification for electronics and hardware – Jan 99

Design and Build by May 99

Install, develop software, and test at ABB Lab – Jun & July 99

Install and test at G-P Mill – Aug & Sept 99
Continue to collect data at G-P Mill with In-plane Sensor and with the present stand-alone ZD system

Determine extended performance of Sensors

Evaluate measurement correlation and response to process variations

Identify potential benefits to operators and to the machine operation
Dimensional Stability: Fundamentals of Cockle

Paper Physics PAC
Fall 1998
Douglas Coffin
Barry Hojjatie
Kennisha Collins

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Strategic Objective

- Reduce the amount of paper rejected because of cockle through improved efficiency in identifying the causes of cockle and/or use of corrective measures to prevent cockle
- Research Line 11

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Research Objectives

- Determine fundamental mechanisms
  - buckling model
  - hygro-buckling tests
- Determine relationships between process, properties, and dimensional instabilities
  - laboratory studies
  - evaluate machinemade papers
- Develop tools to measure and characterize dimensional instabilities.
  - Shadow Moiré System

Project Accomplishments from March 1998 to October 1998

- Handsheet Study of Cockle
- Contacted Printers via e-mail survey
- Hygrobuckling paper accepted by *International Journal of Nonlinear Mechanics*
- Presentation at International Paper Physics Conference
Experimental Study

- Objective: Determine the sensitivity of process variables on sheet flatness
- 8 experiment Plackett Burman design
  ◆ minimize the number of tests
  ◆ 3 repetitions
- 6 process variables
- Measured Sheet Topography

Experimental Program

- Once Dried Hardwood Kraft Pulp
- Noble and Wood Handsheets
- Variables
  ◆ Freeness: 350 and 500 CSF
  ◆ Basis Weight: 70 and 90 gsm
  ◆ Forming: standard, modified
  ◆ Wet press: 60 psi and 0 psi
  ◆ Restraint: no blotters, one blotter
  ◆ Drying Temp: 110 and 90 °C
Making Cockled Handsheets

- Freely Dried Sheets
  - sheets tend to curl and form large waves
- Fully Restrained Dried Sheets
  - tend to be very flat
- Partially Restrained, air-dried sheets
  - form waves but not cockle
- Partially Restrained and Dried on Hot Plate
  - formed cockle

Cockle in Handsheet

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**Topography Measurement**

- Shadow Moiré System
  - measures field topography
- Record height from best fit plane
  - mean height is zero
  - height as a function of position

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**Plackett-Burman HandSheets**

<table>
<thead>
<tr>
<th>Sheet</th>
<th>CSF</th>
<th>gsm</th>
<th>Forming</th>
<th>Press (psi)</th>
<th>Restraint (blotters)</th>
<th>Drying Temp °C</th>
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<td>1</td>
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<td>70</td>
<td>modified</td>
<td>60</td>
<td>0</td>
<td>110</td>
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<td>90</td>
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<td>1</td>
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</tr>
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</table>
Example of Results

CSF: 350  BW: 70 gsm
Forming: modified Wet Press: 60 psi
Blotters: 0  Temp: 100 °C

CSF: 500  BW: 70 gsm
Forming: modified Wet Press: 0 psi
Blotters: 1  Temp: 90 °C

Region: 1.5 X 1.5 inches

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Indicated Sensitivities

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<th>Maximum Height</th>
<th>St. Dev. Height</th>
<th>Number of Peaks</th>
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<td>Restraint</td>
<td>Second Press</td>
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<td>Forming</td>
<td>Forming</td>
<td>Basis Weight</td>
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<tr>
<td>Drying Temperature</td>
<td>Wet Press</td>
<td>Restraint</td>
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<tr>
<td></td>
<td>Drying Temperature</td>
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Sheet flatness was improved with
increased restraint
improved forming
lower drying temp
higher basis weight

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Cockle After Exposure to High Humidity

- One sheet of each type was exposed to 90% Rh for 24 hours then placed at 50% Rh
- topography measured before and after exposure
- calculated percent change in standard deviation of the height

Before and After High RH

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Effect of High RH Exposure

RESTRAINT showed largest sensitivity

As restraint increased, percent change in height decreased

Formation and second press also affected change in height

Preliminary Tests on Varying Restraint

- Varying Restraint During Drying
  - Noble and Wood Handsheet Dried Between Blotters
  - Hung Vertically
  - Clamped on one end
  - weight suspended from paper on the other end
- Increased weight lead to less cockle, but not always a flatter sheet
Printer Survey

- Contacted 30 Printers via the web
- E-mailed questions about flat paper
- Got four responses
  - curl, wavy edges are problem
  - problem with duplex printing

Project Schedule

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<tr>
<th>TASK</th>
<th>98a</th>
<th>98b</th>
<th>99a</th>
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Next Step

- Complete Study of Handsheets
  - focusing on
    - restraint
    - rate of drying
    - formation
    - pressing
  - Focus on Problems with second side printing
  - moisture
  - temperature
  - rate

Confidential Information - not for public disclosure
(For IPST Member Company's Internal Use Only)

Other Avenues of Research

- Eric Carlson: MS 2000 Modeling Moisture Induced Sheet Buckling

- F021: Drying Productivity, Fred Ahrens
  - Evaluate cockle from sheets produced in drying studies

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Accelerated Creep Mechanisms

Doug Coffin
Chuck Habeger

Miranda Bliss
Kennisha Collins
Barry Hojjatie
cyclic 30 to 80 % RH
2 hour cycle

constant 80 % RH
Quantification of Accelerated Creep

Accelerated creep $\equiv$

slope of the creep vs. log time curve at high humidity
divided by the slope under cyclic humidity

cyclic 30 to 80 % RH
2 hour cycle

c_{w}
c_{c}

constant 80 % RH

\[ a.c. = \frac{S_c}{S_w} \]
Accelerated Creep is a Secondary Phenomenon.

A) Stress concentrations develop from swelling during sorption.

B) Many materials creep more under cycling load than a constant, average load.

C) Moisture cycling insures that stress spikes are distributed in time through the material, and therefore overall creep is amplified.

Accelerated creep lives in the creep constitutive equation.

Special microscopic models are unnecessary to explain accelerated creep.

A deeper understanding of accelerated creep may come from a deeper understanding of swelling, creep, and diffusion, but not from new accelerated creep mechanisms.
We say that a material might do accelerated creep if it creeps more under cyclic load than at a constant load.

Does paper creep more under cyclic load than at a constant load?

Let's see!
How can we account for this kind of behavior?

Begin by looking at Brezinski creep curves.
Paper Creep Strain
as a Function of Log. Time at Different Loads

INITIAL STRESS,
KG./SQ. MM.

6.19
5.70
4.62
3.60
2.06

TOTAL FIRST-DEGREE DEFORMATION, %

TIME, SEC.
Accelerated creep is a result of extra creep under cyclic load.

If we assume that creep rate depends only on the instantaneous stress and strain, we can construct the creep constitutive equation under varying load from Brezinski creep curves.

Let me show you how.
Compare

a) creep at 4.62 kg/mm² for 2100 sec.

with

b) creep at 4.62 kg/mm² for 2000 sec., followed by creep at 5.70 kg/mm², follow by creep at 3.60 kg/mm² for 50 sec.
Assuming creep rate depends only on the immediate stress and strain and using Brezinski master creep curves, we construct a creep constitutive model for paper:

$$d\varepsilon = A\sigma \cosh(\alpha\sigma)e^{-\xi_\sigma/B\sigma} dt + d\sigma/E + d\varepsilon_h,$$

where

$E$ is the elastic modulus,

$A$ and $B$ are creep parameters taken from the master creep curve,

and

$d\varepsilon_h$ is the hygroexpansive strain.
Load Cycling with Paper Constitutive Equation

Total strain as a function of cycle time for constant average load creep (solid line) and cyclic load (dotted line) as a function of cycle times.

Creep strain as a function of cycle time for constant average load creep (solid line) and cyclic load (dotted line) as a function of cycle times.

$$A = 3.21 \times 10^{-11}$$ slope of creep compliance versus In time

$$E = 5 \times 10^9$$ Elastic modulus

$$\alpha = 3.4 \times 10^{-7}$$ In time shift per stress increment

$$t_0 = 0.1$$ number of cycles for kick in of secondary creep

$$\sigma(0) = 1 \times 10^7$$ initial stress

$$\varepsilon_0 = 2 \times 10^{-3}$$ initial elastic strain

$$c = 0.5$$ load cycling amplitude

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By combining elements with Brezinski master creep curve constitutive relations, we can make a simple mathematical model of accelerated creep.
Paper-Like Constitutive Equation

differential creep element
\[ \text{d} \varepsilon_c = A \sigma \cosh(\alpha \sigma) \]
Moisture swelling and extra creep from cyclic loading are necessary, but not sufficient conditions for accelerated creep.

in addition

(A)

Moisture-Gradient-Driven Accelerated Creep

Moisture cycling results in moisture gradients for a significant portion of the creep time.

or

(B)

Heterogeneity-Driven Accelerated Creep

The material is heterogeneous in its response to moisture.
Moisture-Gradient-Driven Accelerated Creep with Paper-Like Constitutive Equation

**Creep**

- **Elongation** vs. **Number of Moisture Cycles**
- **Load Sharing**

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Preliminary Experimental Results

(A)

Cellophane

People who expouse fiber-structure-based explanations of accelerated creep take heart that cellophane is reported to not do accelerated creep.

The quoted experiment, however, was conducted under very slow sorption conditions, and we doubt the conclusion drawn from it.

Cellophane experiments needed repeating.
Preliminary Experimental Results

(B)

(Sorption Time)/(Cycle Time)

If cycle time is long compared to sorption time, accelerated creep should disappear because the portion of time in which stress concentrations are operative is small.

If cycle time is short compared to sorption time, accelerated creep should disappear because there is no moisture cycling in the interior.
Creep Stain [%]

Log Time [seconds]

Constant 80% RH

Cyclic 30 to 80% RH

20 min cycles
80 min cycles
320 min cycles

A: Single Ply TMP
AAAA: Four Plies TMP
Accelerated creep versus cycle time in minutes of samples of different caliper
Preliminary Experimental Results

(C)

Ply-Level Heterogeneity?

Compare accelerated creep in multiply sheets with different combinations of TMP and bleached kraft furnishes.
Preliminary Experimental Results

(D)

Fiber-Level Heterogeneity?

Compare accelerated creep in pulp blends with different combinations of TMP and bleached kraft fibers.
Time [seconds]  
Strain [%]

- A = TMP
- AB = blend of TMP and kraft fibers
- B = bleached kraft
Fiber Accelerated Creep

Fibers generally don't show accelerated creep. e.g. nylon 6,6 and wood fibers

For us,
this is because they sorb too fast.
Moisture gradients exist for a small portion
of a cycle time.

The one exception is Kevlar fibers,
which, thankfully, sorb much slower than other fibers

However, Kevlar fibers
exhibit a "sub-linear" creep behavior!
Fig. 3  Room temperature creep curves for Kevlar 49 fibres
Cyclic Loading of K-29, Oct 9 Test

\[ P_l = 3.1 \text{ gr}, \quad P_{\text{mid}} = 5.7 \text{ gr}, \quad P_h = 8.3 \text{ gr} \]

Length = 232 mm

RH = 92%

Sample preconditioned for 18 hrs at 92% RH

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(for IPST Member Company's Internal Use Only)
Creep of K-29 subjected to cyclic RH

Test Date: Oct. 20, 1998

- Load = 3.1 gr
- Temperature = 22°C
- Length = 235 mm
- Sample preconditioned for 24 hrs at 95% RH
Major Revelation:

Accelerated Creep is Creep.

Reducing creep stabilizes paper in cyclic humidity environments.
1. TYPICAL FIRST-CREEP CURVE AT 3.5 KG. LOAD

SECOND-CREEP CURVES AT 3.5 KG. LOAD
FOLLOWING FIRST TESTS OF THE FOLLOWING DURATION:

<table>
<thead>
<tr>
<th>CREEP</th>
<th>RECOVERY</th>
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<tbody>
<tr>
<td>2. 200 SEC.</td>
<td>1,640,000 SEC.</td>
</tr>
<tr>
<td>3. 2,000</td>
<td>1,455,000</td>
</tr>
<tr>
<td>4. 30,000</td>
<td>1,774,000</td>
</tr>
<tr>
<td>5. 587,000</td>
<td>1,251,000</td>
</tr>
</tbody>
</table>

Fig. 13. Second-Creep Curves Following First-Creep Tests of Varying Duration for Bauschard 21.
Questions to Answer before Practical Pursuit of Mechanical Conditioning to reduce Creep and Accelerated Creep

1) What load levels must be administered for how long at what moisture content to achieve beneficial results?

2) How robust is the improvement? Can time, loading, or moisture cycling after mechanical conditioning reverse the effect?

3) Will mechanical conditioning increase time to failure under load as-well-as decrease accelerated creep?

4) How does mechanical conditioning effect convertibility?

5) Can a paper be stabilized in compression by conditioning in tension and vice versa, or is creep rate increased by load of opposite sign?

6) Does on-machine CD restraint help or hinder CD compression stability in cyclic environments?

7) Does mechanical conditioning during normal manufacture account for some of the performance differences between papers and between directions in a paper?
IMPROVING THE REFINING OF CHEMICAL PULPS

Project F024

John F. Waterhouse
Hiroki Nanko
Miranda Bliss

October 28, 1998
PROJECT OBJECTIVE

Determine how changes in fiber structure and the means to produce them, are related to improved paper machine productivity, paper quality, and reduced energy consumption.

Relevant Research Lines:
10. Reduced net energy consumption per ton by 30% compared to "97" levels.
PROJECT DELIVERABLES

1. Methodology for determining a pulp's response to refining.


SHORTER TERM OBJECTIVES

1. Establish methods for producing selected changes in fiber structure.
2. Establish methods to measure and characterize these changes in fiber structure.
3. Determine the relative impact of these changes on drainage, water removal, and paper properties.
4. Determine how selected pulp variables influence these changes in fiber structure.
5. Determine the extent to which these changes can be produced in production refiners.
SELECTED CHANGES IN FIBER STRUCTURE

- Internal Changes in Fiber Structure
- External Changes in Fiber Structure
- Fines Production
- Fiber Length Reduction
- Changes in Fiber Curl

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PULP VARIABLES AFFECTING REFINING ACTION

- Pulping and bleaching processes
- Species and morphology
- Pulp rheology
- Consistency and state of flocculation
- pH and ionic state
- Fiber deformation behavior
- Chemical composition of cell wall
SUMMARY OF ACTIVITY
(March - October 1998)
and Outline of Presentation

- Joint Pulping-Bleaching-Refining Project with Chemical and Biological Sciences Division.
- Simulation of Production Refining - EW Refiner
- Investigation of a fibers propensity to "cutting"
- Investigation of a fibers propensity to fibrillation.
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  - Investigation of a fibers propensity to fibrillation
### COOPERATIVE PROJECT BETWEEN CHEMICAL & BIOLOGICAL SCIENCES AND FIBER AND PAPER PHYSICS DIVISIONS

<table>
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<th>Material &amp; Cook</th>
<th>Kappa No. Actual</th>
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<th>Bleaching DED</th>
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<td>S.P. chips ⇒ conventional kraft</td>
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<td>-</td>
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<td>yes</td>
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<td>6</td>
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<td>*</td>
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<td>7</td>
<td>Kappa 30 ⇒ oxygen</td>
<td>10.7</td>
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FREENESSION VARIATION WITH KAPPA NO.
FREENESS CHANGE WITH KAPPA NO.
(0 revs to 3000 revs)

IPST Confidential Information - Not for Public Disclosure (For IPST Member Company's Use Only)
FINES PRODUCTION VS KAPPA NO
(0 revs to 3000 revs. PFI mill)

Delta % Fines

Kappa No.
FINES PRODUCTION VS KAPPA NO.
(0 revs. to 3000 revs. PFI mill)
FREENESSION CHANGE VS FINES INCREASE
(0 revs to 3000 revs PFI mill)

IPST Confidential Information - Not for Public Disclosure (For IPST Member Company's Use Only)
VARIATION OF WRV WITH KAPPA No. (fines free)
VARIATION OF WRVfines WITH KAPPA No. (unbeaten)
VARIATION OF WRV fines WITH KAPPA No. (beaten)

IPST Confidential Information - Not for Public Disclosure (For IPST Member Company's Use Only)
# Iron and Palladium Colloid Staining Results

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<th>Pd Stain</th>
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<td>μgms/gm</td>
<td>μgms/gm</td>
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<tr>
<td></td>
<td>0 revs</td>
<td>3000 revs</td>
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<tr>
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<td>110.1</td>
<td>12,450</td>
<td>27,000</td>
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<tr>
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<td>16,800</td>
<td>42,100</td>
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<td>17.1</td>
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<td>38,600</td>
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<td>20.4</td>
<td>18,200</td>
<td>41,100</td>
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<td>15.0</td>
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<tr>
<td>10.7</td>
<td>20,100</td>
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# TAPPI Handsheet Properties for Unbeaten Pulps

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**Kraft Delignification**

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<td>1.61</td>
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TAPPI HANDSHEET PROPERTIES FOR PULPS BEATEN TO 3000 REV. PFI MILL

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<td>2.75</td>
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**KRAFT DELIGNIFICATION**

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<td>10.7</td>
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<td>94.6</td>
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**KRAFT 30K + OXYGEN DELIGNIFICATION**
VARIATION OF TEAR INDEX WITH KAPPA No.

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SUMMARY OF ACTIVITY
(March - October 1998)
and Outline of Presentation

• Joint Pulping-Bleaching-Refining Project with Chemical and Biological Sciences Division.

• Simulation of Production Refining - EW Refiner

• Investigation of a fibers propensity to "cutting"

• Investigation of a fibers propensity to fibrillation.
SEVERITY OF REFINING

CHANGE IN TENSILE INDEX WITH SEVERITY OF REFINING AT CONSTANT SPECIFIC ENERGY
(AFTER KEREKES, R.)

CHANGE IN TENSILE INDEX

SEVERITY OF IMPACTS = P/C
NUMBER OF IMPACTS = C/M
Where C, P, & M are C-factor, Power, & Thru-put

FIBER RUPTURE ENERGY

SOFTWOODS → 10

HARDWOODS → 60

SEVERITY OF IMPACT KJ/Kg

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SUMMARY OF ACTIVITY
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- Investigation of a fibers propensity to fibrillation.

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VARIATION OF WET ZERO SPAN STRENGTH WITH KAPPA No.

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SUMMARY OF ACTIVITY
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earlywood fiber

latewood fiber

Kappa 30 => oxygen treatment Kappa 10.7
FUNDAMENTALS OF INTERFIBER BONDING

IPST Project F025

Hiroki Nanko
Shaobo Pan

Paper Physics PAC
October 28, 1998

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Current Objectives

- Determining the effects of papermaking chemicals on paper structure and properties

- Evaluation of refining effects on fiber structure [F024]
Effects of Papermaking Chemicals on Paper Structure and Property

To know "how bonding agents work":

- Visualize bonding agents by TEM
- Examine the location and distribution of bonding agents throughout papermaking processes
- Examine the effects of bonding agents on the manner of bond breakage
Bonding Agents to Observe

- Starch, Cationic starch
- Natural gum
- Polyacrylamid
- Others
Visualization Strategy (I)  
Negative Staining / TEM  

Stain: Uranyl Acetate  

Virus  

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Visualization Strategy (II)
Metal Colloid Staining / TEM

- Detect negative charge by positively charged metal colloid (Fe colloid, Ag colloid)
- Detect positive charge by negatively charged metal colloid (Au colloid, Pt colloid)

[Au colloid]
Fibrils + Polymer Sizing agent + Au colloid

0.1um
Au Colloid Staining for TEM

- Pulp: softwood BKP (dry pulp)
- Beating: PFI mill (3500 rev.)
- Staining:
  - Add polymer to pulp suspension and stir it for 10 min
  - Add Au colloid to pulp suspension
  - Take sample on a grid for negative staining
Visualization of Cationic Starch by Au Colloid

[Starch Structure]

[Tertiary Aminoalkyl Ethers of Starch]
\[
\text{starch} - \text{O} - \text{CH}_2\text{CH}_2\text{N(CH}_2\text{CH}_3)_2 \text{Cl}^-
\]

[Quaternary Ammonium Starch Ethers]
\[
\text{starch} - \text{O} - \text{CH}_2\text{CH} - \text{CH}_2\text{N(CH}_3)_3 \text{Cl}^-
\]

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Cationic Starch on Fibril Surface

cationic starch (1%) + Au colloid + negative staining
Arrangement of Au colloid on Fibril Surface

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Dissolved Cationic Starch Molecules

cationic starch (5%) + Au colloid + negative staining
Cationic Starch on Fiber Surface
Cationic PAM on Fibril Surface

cationic PAM (3%) + gold colloid + negative staining

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Linear arrangement of colloid particles on the fibril surface appears to showing that both CS and CPAM tend to bond electro statically to the hemicelluloses which aliened along the microfibrils. CS aligned more the CPAM.

1% of CS added to the beaten pulp almost completely covered the surface of fibril, however, fiber surface was partially covered. More than 1% of CS added increased free CS molecules free from pulp.

0.3% of CPAM added to the beaten pulp completely adsorbed to the fibril surface. CPAM molecules were still associated with fibrils although some part of molecules was not staying on the fibril surface.
Staining of Starch for Light Microscopy

- I KI Reaction
- Periodic Acid-Schiff’s (PAS) Reaction

polysaccharides  periodic acid  dialdehide  Schiff’s reagent  purplish red compound
Staining of Starch for TEM Observation

- periodic acid - thiocarbohydrazide - silver protein (PA-TCH-SP) Reaction

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Staining of Starch for LM and TEM

- Limitations of IKI staining for starch in paper
  - causes swelling and dissolution of starch
  - causes migration of starch
  - only for light microscopy at low magnification (temporary slides)

- Alternative method
  - formaldehyde cross-linking treatment of paper
  - embedding in epoxy resin
  - section staining by polysaccharide staining reaction

- Advantages
  - no swelling and no migration of starch by cross-linking treatment
  - permanent slides for LM at high magnification
  - high resolution TEM observation

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Visualization of Starch in Glue Lines of Corrugated Board
Glue Line of Corrugated Board
example of poor bonding
Structure of Glue Line in Corrugated Board

Completely gelled starch at high strength region and ungelled granules at exterior region

Ungelled starch grains at high pressure region

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Visualization of Surface Sizing in Milk Carton

Cationic starch stained by Au Colloid (center). Surface sized layers by starch remained unstained.

Cationic starch stained by Au colloid

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Problems to Be Solved

- Control of pH for negative staining
  - acidic: uranyl acetate
  - neutral: phosphotungstic acid
  - basic:  

- Increase applicable metal colloids
  - particle size (small, medium, large)
  - stable pH conditions (acidic, neutral, basic)
  - charge (negative, positive)

- Application of colloid staining technique to sizing agents
Deliverables

- How bonding agents work
- Strategy of improving the effectiveness of bonding agents