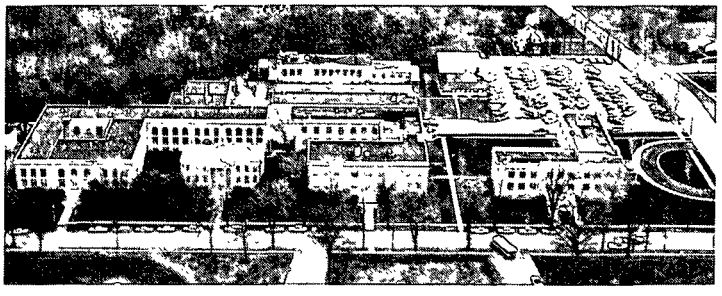
M. LORENZ



THE INSTITUTE OF PAPER CHEMISTRY, APPLETON, WISCONSIN

STATUS REPORTS

To The

PAPER PROPERTIES AND USES

PROJECT ADVISORY COMMITTEE

April 2-3, 1985
The Institute of Paper Chemistry
Continuing Education Center
Appleton, Wisconsin

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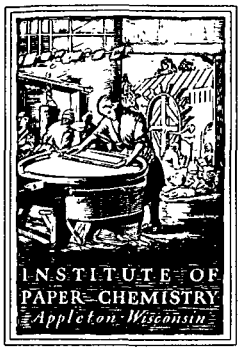

THE INSTITUTE OF PAPER CHEMISTRY
Post Office Box 1039
Appleton, Wisconsin 54912
Phone: 414/734-9251
Telex: 469289

March 14, 1985

TO: MEMBERS OF PAPER PROPERTIES AND USES PROJECT ADVISORY COMMITTEE

The status reports for the upcoming Paper Properties and Uses PAC meeting are attached for your review. The meeting convenes at 8:30 Tuesday morning, April 2, in the Seminar Room of the Continuing Education Center at IPC.

A pink security card, giving the combination to the outside CEC door, is attached for those of you staying at the center. Enclosed with the status reports you will find an updated meeting agenda, a list of committee members, and a brochure containing a listing of current M.S. and Ph.D. student research.

The Tuesday evening session is concerned with how one might control web MD and CD mechanical properties during paper manufacture. We are hoping for Committee input.

If you have any questions or comments give me a call. I look forward to seeing you in April. Best regards.

Sincerely,

Gary

Gary A. Baum
Director
Paper Materials Division

GAB/sb
Enclosures

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MEETING AGENDA

PAPER PROPERTIES AND USES
PROJECT ADVISORY COMMITTEE

April 2-3, 1985
The Institute of Paper Chemistry
Continuing Education Center
Appleton, WI

Tuesday -- April 2

8:30 am	Welcome/Introductions	Homan/Baum
8:45	PROJECT REVIEWS	
	Measurement of Fiber Properties and Fiber-to-Fiber Bonding	Hardacker
	Fundamentals of Internal Strength Enhancement	Stratton
10:15	COFFEE BREAK	
10:30	PROJECT REVIEWS	
	Compressive Strength	Waterhouse/Whitsitt
	Student Research	Bither
	Board Properties and Performance	Whitsitt/Halcomb
12:00 pm	LUNCH	
12:45	TOUR OF PAPER MATERIALS DIVISION LABORATORIES	
2:30	PROJECT REVIEWS	
	Combined Stress and Failure Processes	Waterhouse
3:00	COFFEE BREAK	
3:30	PROJECT REVIEWS	
	Process, Properties, Product Relationships	Baum/Habeger
	Student Research	Berger
	On-Machine Measurement of Paper Mechanical Properties	Baum

5:15	SOCIAL TIME	
6:00	DINNER (CEC Dining room)	
7:15	SPECIAL TOPIC: Paper Machine Control	Committee and Staff

Wednesday -- April 3

7:15 am	BREAKFAST (CEC Dining Room)	
8:00	DISCUSSION OF PROJECTS	Committee
10:00	COFFEE BREAK	
10:30	DISCUSSION OF PROJECTS (cont.)	Committee
11:15	CLOSING COMMENTS	
	Next meeting October 22-23, 1985	
11:30	ADJOURNMENT/LUNCH (CEC Dining Room)	

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PROJECT ADVISORY COMMITTEE

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3/11/85
*date of retirement

THE INSTITUTE OF PAPER CHEMISTRY

Appleton, Wisconsin

Status Report

to the

PAPER PROPERTIES AND USES

PROJECT ADVISORY COMMITTEE

Project 3527

MEASUREMENT OF FIBER PROPERTIES AND FIBER-TO-FIBER BONDING

April 2-3, 1985

PROJECT SUMMARY

Date:	3/11/85
Budget:	$85,000
Period Ends:	6/30/85
Project No.:	3527

PROJECT TITLE: MEASUREMENT OF FIBER PROPERTIES AND FIBER-TO-FIBER BONDING

PROJECT STAFF: K. W. Hardacker/G. A. Baum

PROGRAM GOAL: Bring new attributes to wood-based products.

PROJECT OBJECTIVE:

The ultimate project objective is to define steps for making a paper of superior strength and with superior performance at high humidities. The immediate objective is to develop instrumentation to measure fiber mechanical properties in order to better understand the action of water in degrading fiber strength, stiffness, and fiber-fiber bonding.

PROJECT RATIONALE, PREVIOUS ACTIVITY, and PLANNED ACTIVITY FOR FISCAL 1985-86 are on the attached 1985-86 Project Form.

SUMMARY OF RESULTS LAST PERIOD: (March 1984 - September 1984)

All instrument components had been received. Final assembly was underway.

SUMMARY OF RESULTS THIS PERIOD: (September 1984 - March 1985)

The instrument has been assembled and is undergoing operation tests, debugging, and calibration. The details are presented in the attached report.

PROJECT TITLE: Measurement of Fiber Properties and Fiber-to-Fiber Bonding

PROJECT STAFF: K. Hardacker/G. A. Baum

PRIMARY AREA OF INDUSTRY NEED: Properties related to end uses

PROGRAM AREA: Moisture tolerant, superior strength paper and board.

Date: 2/12/85
Budget: $65,000
Period Ends: 6/30/86
Project No.: 3527
Approved by VP-R:

PROGRAM GOAL: Bring new attributes to wood-based products.

PROJECT OBJECTIVE:

The ultimate project objective is to define steps for making a paper of superior strength and with superior performance at high humidities. The immediate objective is to develop instrumentation to measure fiber mechanical properties in order to better understand the action of water in degrading fiber strength, stiffness, and fiber-fiber bonding.

PROJECT RATIONALE:

At present, commercial papers do not attain strength levels that realize the full potential of existing wood fibers. Most paper mechanical properties are markedly degraded with increasing paper moisture content. We need to better understand the nature of these changes in fiber properties and fiber-to-fiber bonding with increasing moisture content if we are eventually to improve the moisture tolerance of paper.

RESULTS TO DATE:

There has been limited activity on this project to date. A literature search has been conducted. Ultrasonic techniques have been used to measure the in-plane and out-of-plane elastic constants of paper up to moisture contents of 60%. Above about 40% moisture, the water in the sheet dominates the measurement.

An instrument to measure axial or transverse fiber mechanical properties and fiber-fiber bond strength has been designed and constructed. It is currently being adjusted and calibrated.

PLANNED ACTIVITY FOR THE PERIOD:

This effort represents a start on one of our expansion projects. The short term goals are to make measurements of fiber properties as a function of moisture content and to develop new instruments and techniques, as needed, to measure fiber properties and fiber-to-fiber bond strength vs. moisture content.

POTENTIAL FUTURE ACTIVITIES:

Construction of the stated piece of equipment will lead to a number of applications in other research areas.

Status Report

MEASUREMENT OF FIBER PROPERTIES AND FIBER-FIBER BONDING

Project 3527

One facet of the development of moisture tolerant, superior strength paper is the determination of the effects of moisture on the individual fibers and on the bonds between the fibers. Measurements of the following properties are indicated:

1. Fiber axial tensile load/elongation characteristic
   - Breaking stress
   - Breaking strain
   - Work to rupture
   - Initial modulus
2. Tensile characteristics of various bonded-fiber-pair configurations.
3. Fiber transverse tensile load/deformation characteristics.
4. Fiber (and crossed fibers) transverse compression load/deformation characteristics.
5. Fiber cell wall shear modulus.

A literature survey was made to determine how other investigators had made these measurements. No single method appeared well suited to making all the desired measurements. In fact, the Institute's existing Fiber Load Elongation Recorder, with suitable fixtures, could be used for measurements 1-4 except for marginal sensitivity for the transverse measurements.

Rather than try to upgrade the Fiber Load Elongation Recorder, it was decided to design and construct a versatile new instrument with adequate range and sensitivity.

The instrument has been assembled and is shown in Fig. 1.

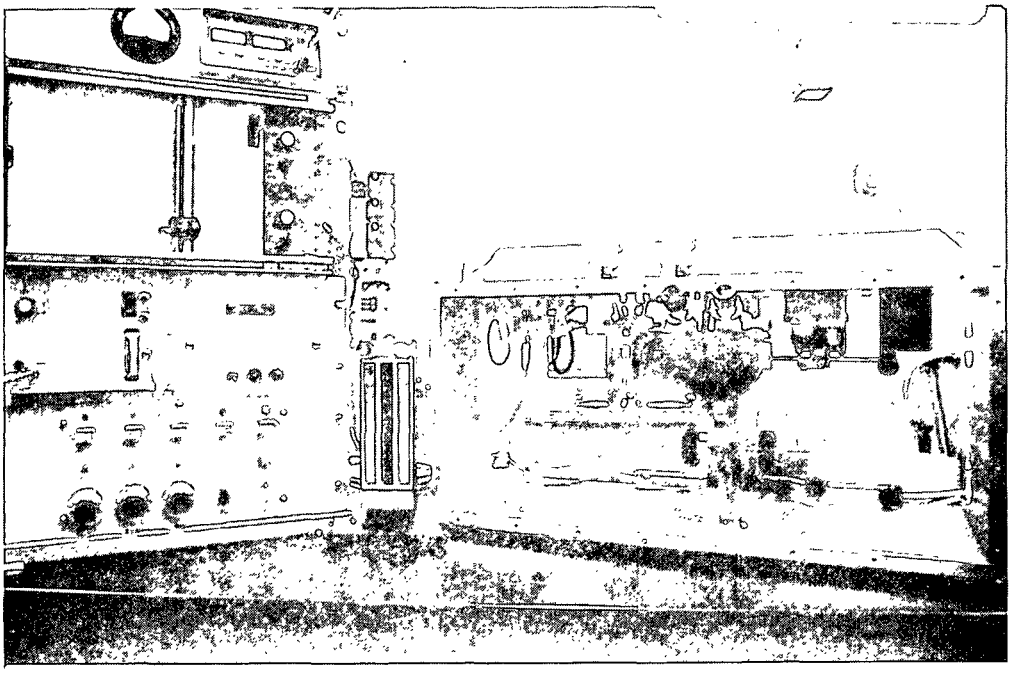

Figure 1. The Fiber Load/Elongation Recorder, Model II.

The core of the instrument is the specimen handling system in the right hand side of the photo. A schematic of this is shown in Fig. 2, where an electronic weighing cell, A, is suspended beneath a mounting plate, B, by means of four flexure springs, C. A dc servo motor, D, turns a differential screw, E, pulling or pushing the weighing cell to apply a tensile or compression load to a specimen mounted between the clamps, F. The right hand clamp may be positioned along the test axis by the compound microscope focusing mechanism, G, and be locked in place by the clamp, H. Specimen extension or compression is measured between this fixed clamp and the opposing, movable clamp. A capacitive displacement transducer, I, supported by the pillar, J, senses the position of the movable clamp.

A stereoscopic microscope is mounted to permit viewing and/or photographing the specimens during mounting and testing. Special jigs and holders are being developed for mounting the specimens in the various configurations desired.

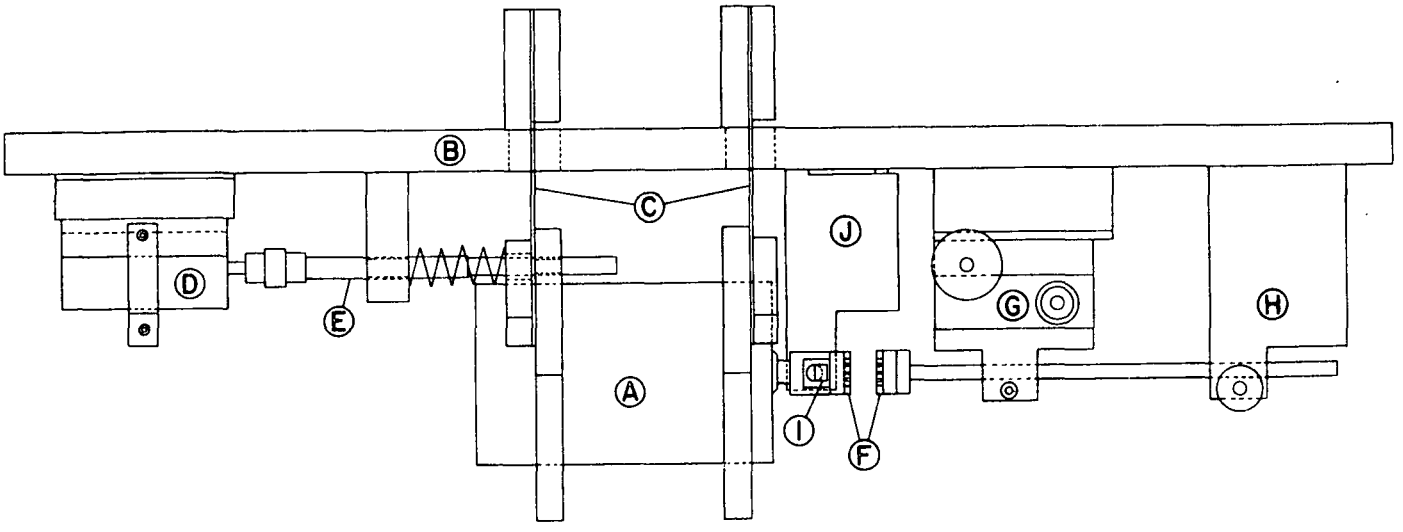

Figure 2. Side view of the Fiber Load/Elongation Recorder, Model II. Scale: 1 in = 5 in. A - electronic weighing cell, B - mounting plate, C - flexure springs, D - dc servo motor, E - differential screw, F - clamps, G - microscope focusing mechanism, H - clamp, I - transducer, and J - pillar.

Dry air and air saturated with moisture are mixed in any desired ratio in the small mixer shown in the center of Fig. 1, then allowed to exit so as to envelope the specimen and set its moisture content. The relative humidity and temperature of the mixed air stream are sensed, then displayed on a readout at the top of the equipment rack shown on the left in Fig. 1.

The signal for driving the dc motor is derived by comparing the signal from the load or elongation sensor with a linear ramp reference voltage. Thus, testing may be done either at constant rate of loading or constant rate of elongation. The ramp generator (at the bottom of the rack in Fig. 1) supplies the ramp and the necessary controls for varying the rate at which the tensile or compression test is performed and setting the load or elongation limits between which the loading and unloading may be cycled.

Calibration of the ramp generator has been completed. As constructed, specimen load and deformation rates are infinitely adjustable between the following limits:

Elongation cell I	(0.05 mm range, 0.05 μm sensitivity)
	0.026 μm/sec to 15 μm/sec
Elongation cell II	(0.25 mm range, 0.25 μm sensitivity)
	0.130 μm/sec to 74 μm/sec
Load cell A	(50 g range, 1 mg sensitivity)
	0.05 g/sec to 30 g/sec
Load cell B	(400 g range, 5 mg sensitivity)
	0.42 g/sec to 242 g/sec

The measured load and elongation signals are applied to an x-y recorder mounted in the rack. They may, of course, also be fed to a digital processor (not provided at present) when appropriate.

Work is continuing with load and elongation calibration and the development of fixtures and procedures for mounting and testing the fibers to measure the properties listed on the first page.

K. W. Hardacker
3/11/85

THE INSTITUTE OF PAPER CHEMISTRY

Appleton, Wisconsin

Status Report

to the

PAPER PROPERTIES AND USES

PROJECT ADVISORY COMMITTEE

Project 3526

FUNDAMENTALS OF INTERNAL STRENGTH ENHANCEMENT

April 2-3, 1985

PROJECT TITLE: Fundamentals of Internal Strength Enhancement

Date: 3/11/85
Budget: $220,000
Period Ends: 6/30/85
Project No.: 3526

PROJECT STAFF: R. A. Stratton/J. J. Becher

PRIMARY AREA OF INDUSTRY NEED: Properties related to end use

PROGRAM AREA: Moisture tolerant, superior strength paper and board

PROGRAM GOAL: Bring new attributes to fiber based products

PROJECT OBJECTIVE:

To improve internal strength and moisture tolerance in paper and paperboard. The short terms goals are to establish those parameters fundamental to inter-fiber and intra-fiber bonding in conventional and ultra high yield pulps and to control these parameters, if possible, by chemical or mechanical treatments.

PROJECT RATIONALE:

Major limitations of paper and board for many uses are low internal bond strength and poor moisture tolerance. Improved internal strength and enhanced moisture resistance would allow a number of present grades to be produced using less fiber and would allow new end uses to be developed.

Size pressing is one way currently used to enhance internal strength. If this operation could be eliminated, or substantially changed to improve paper machine runnability, paper machine productivity could be also significantly improved.

SUMMARY OF RESULTS LAST PERIOD: (March 1984 - September 1984)

(1) With respect to the use of polymeric additives, extended studies with the polyacrylic acid/polyamide polyamine epichlorohydrin (PAA/PAE) combination revealed that the presence of a third polymer such as polyvinyl alcohol (PVA) provided relatively small improvements in tensile properties. This applies to the typical yield softwood unbleached kraft pulps used in this study.

(2) PAA/PAE ratio was not found to be critical to strength properties at addition levels of 1% or less.

(3) Strength properties tended to increase slightly with increase in PAA molecular weight but, in general, little advantage was obtained at a PAA molecular weight greater than 104,000.

(4) The repulpability of papers containing CMC/PAE or PVA/PAE/PAA was found to be roughly comparable to those containing PAE alone although more intensive pulping may be required.

(5) Analysis of CMC/PAE and PAA/PAE treated papers using Fourier Transform Infrared (FTIR) indicated that covalent bonding occurred between the polymeric additives and there was some indication that covalent bonding also occurred between the additives and cellulose.

(6) The vertical polarized light method has been adapted for the measurement of bonded area of individual fiber/fiber bonds. Techniques were developed for measuring the bonded area, bond strength, and locus of bond failure on the same bonded fiber pair.

(7) An instrument has been developed for measuring the dynamic mechanical properties of paper samples by the vibrating reed technique. Temperatures from ambient to 200°C and a range of relative humidities can be encompassed. This instrument will be used to monitor the glass transition temperature of the lignin component in very high yield pulps as a function of chemical additives or derivatization.

SUMMARY OF RESULTS THIS PERIOD: (October - March, 1985)

(1) Work with the duo-polymer systems described in Progress Report One was extended to higher yield pulps which differed in pulping procedures and wood source. Both additive combinations [carboxymethyl cellulose-polyamide polyamine epichlorohydrin (CMC/PAE)] and polyacrylic acid/PAE (PAA/PAE) were found to improve the strength properties of a 57% yield classified softwood unbleached kraft to levels which were greater than those of the 48% yield kraft controls. Extending this study to 88-90% yield lodgepole pine TMP and an 85-89% yield unclassified spruce chemimechanical pulp revealed that one or both of the polymer combinations were effective in these pulps.

(2) Pectins from several sources were examined for sorptive properties on an average yield softwood unbleached kraft and the spruce chemimechanical pulps. While several of these products were adsorbed to some extent, evidence available at this time indicates that they are ineffective as fiber bonding agents; however, this work is incomplete.

(3) The effects of treated and untreated fines on the strength properties of the lodgepole pine TMP are under study.

(4) Chemical analysis of polymer-fiber bonding mechanisms is continuing.

(5) Techniques for forming bonded fiber pairs were improved. The use of the vertical polarized light technique to measure bond area was further developed.

PROJECT TITLE: Fundamentals of Internal Strength Enhancement

PROJECT STAFF: R. A. Stratton/J. J. Becher

PRIMARY AREA OF INDUSTRY NEED: Properties related to end use

PROGRAM AREA: Moisture tolerant, superior strength paper and board

Date: 2/12/85
Budget: $220,000
Period Ends: 6/30/86
Project No.: 3526
Approved by VP-R:

PROGRAM GOAL: Bring new attributes to fiber based products

PROJECT OBJECTIVE:

To improve internal strength and moisture tolerance in paper and paperboard. The short term goals are to establish those parameters fundamental to inter-fiber and intra-fiber bonding in conventional and ultra high yield pulps and to control these parameters, if possible, by chemical or mechanical treatments.

PROJECT RATIONALE:

Major limitations of paper and board for many uses are low internal bond strength and poor moisture tolerance. Improved internal strength and enhanced moisture resistance would allow a number of present grades to be produced using less fiber and would also allow new end uses to be developed.

Size pressing is one way currently used to enhance internal strength. If this operation could be eliminated, or substantially changed to improve paper machine runnability, paper machine productivity could be also significantly improved.

RESULTS TO DATE:

PART ONE: Improved bonding via chemical additives.

Progress Report One was issued in September, 1984. The report covers exploratory work with chemical additives as a means to enhance strength properties, primarily in an average yield softwood unbleached kraft pulp. Results revealed that at least two polymer combinations provided strength levels which were markedly higher than those of the appropriate controls. The additives of major interest were comprised of combinations of carboxymethyl cellulose (CMC) and polyamide polyamine epichlorohydrin (PAE) and a polyacrylic acid (PAA) and PAE. In addition to high levels of dry, moist, and wet tensile properties, these combinations significantly improved extensional stiffness (Et), tensile energy absorption (TEA), and stretch. The effectiveness of these combinations were usually expressed in terms of moist and wet tensile factors which reached levels of 2.6 and 17-18, respectively, compared to 1.8 and 12.8 for the PAE controls. Diffuse reflectance FTIR analysis indicated that covalent bonds were formed in the presence of the polymer combinations.

PART TWO: Fundamentals of bonding.

Studies of the locus of failure of fiber/fiber bonds have shown no clear trends. This was due, we believe, to the variability in our bond-forming technique. Subsequently, new techniques were devised for handling the fibers and forming

the bonds under more controlled pressing conditions. The vertical polarized light method has been adapted for the measurement of bonded area of individual fiber/fiber bonds. Techniques were developed for measuring the bond area, bond strength, and locus of bond failure on the same bonded fiber pair.

An instrument was developed for measuring the dynamic mechanical properties of paper samples or thin wood samples by the vibrating reed technique. Temperatures from ambient to 200°C and a range of relative humidities can be encompassed. This instrument will be used to monitor the glass transition temperature of the lignin component in very high yield pulps as a function of chemical additives or derivatization. It can also be used to measure non-destructively the modulus of paper samples over a range of relative humidities.

PLANNED ACTIVITY FOR THE PERIOD:

This project is complementary to two expansion projects proposed in 1982: one concerned with moisture tolerant products and the other high yield pulps. In addition, another current project (3527) is concerned with the development of instrumentation which will eventually be used in this project.

The following activities are planned for this fiscal year.

Part One:

(1) The use of additives will be extended to other classes of polymeric materials including pectins.

(2) Polymers and combinations thereof providing positive results in average yield pulp will be evaluated in higher yield pulps including TMP and chemimechanical pulps.

(3) The role of fines in the use of chemical additives will be examined.

(4) Study of bonding mechanisms will be continued.

Part Two:

(1) The influence of pulp yield and degree of refining on bond strength and locus of bond failure will be studied using the new instrumentation developed in Project 3527.

(2) The effect of chemical additives (developed in Part One of this project) on bond strength and locus of bond failure will be studied.

STUDENT RELATED RESEARCH

R. Crow, Ph.D.-1984; K. Brigham, Ph.D.-1985; A. Wigsten, Ph.D.-1983; W. McCarthy, M.S.-1984; M. Goulet, M.S.-1986; J. Standley, M.S.-1986.

STATUS REPORT

FUNDAMENTALS OF INTERNAL STRENGTH ENHANCEMENT

Project 3526

SUMMARY

In pursuing work with the two polymer systems described in Progress Report One and at the last PAC meeting, combinations of CMC/PAE and PAA/PAE were evaluated in higher yield pulps which differed in pulping conditions and wood source. The pulps varied in yield from 57% (classified southern pine unbleached kraft) to approximately 90% for a lodgepole pine TMP and a spruce chemimechanical pulp. Results show that increasing the yield of the unbleached kraft pulp from 48 to 57% resulted in a very substantial reduction in tensile properties. However, addition of either CMC/PAE or PAA/PAE increased dry and moist breaking lengths to levels as great as, or greater than, those of the 48% yield controls. It was shown in these studies that increasing the density of the 57% yield controls via wet pressing failed to increase strength to the levels afforded by CMC/PAE or PAA/PAE. It was also found that the 57% yield kraft pulp containing PAA/PAE could be readily sized with a neutral sizing agent without sacrifice in dry and moist tensile properties. Selected results from this series are presented in Table 1.

Upon extending work with the CMC/PAE and PAA/PAE systems to higher yield pulps, one or both of these additive combinations was found to be effective. The CMC/PAE system proved quite effective in the 88-90% yield lodgepole pine TMP whereas the PAA/PAE combination failed to provide a consistent advantage over PAE alone. Possible reasons for this behavior are under study. On the other hand, both CMC/PAE and PAA/PAE were found to be effective in an 85-89% yield spruce chemimechanical pulp in which case the untreated pulp controls were significantly stronger than the 57% yield kraft and the 88-90% yield TMP.

Table 1. The effectiveness of bonding agents in 57% yield softwood unbleached kraft (classified pulp).

Set No.	Pulp	Additives, % Based on Fiber	Wet Pressing Conditions	Dry Breaking Length, Km	Moist Breaking Length, Km	Wet Breaking Length, Km
1	48% yield softwood unbl. kraft (control)	None	5 min at 50 psig	3.35[a]	1.74[a]	0.102[a]
2	57% yield softwood unbl. kraft (control)	None	5 min at 50 psig	1.54	0.66	0.018
3	57% yield softwood unbl. kraft (control)	None	15 min at 100 psig[b]	1.66	0.68	0.069
4	57% yield softwood unbl. kraft	PAE,1.0	5 min at 50 psig	2.80	1.54	0.721
5	57% yield softwood unbl. kraft	PAE,1.0;CMC,0.4	5 min at 50 psig	3.23	1.87	0.994
6	57% yield softwood unbl. kraft	PAE,1.0;PAA,0.2	5 min at 50 psig	4.03	2.26	1.13
7	57% yield softwood unbl. kraft	PAE,1.0;PAA,0.2 Alkenyl Succinic Anhydride, 0.25	5 min at 50 psig	4.47	2.61	1.08

[a]Average of three sets of handsheets.
[b]The density in this case was 0.345 g/cc compared to 0.320 for 1% PAE, 0.341 for CMC/PAE, 0.360 for PAA/PAE, and 0.300 for the controls pressed at 50 psig.

The potential of pectins from various sources as bonding agents for paper is currently under study. A preliminary screening was carried out to determine if these materials are retained by papermaking fibers. Retention measurements were made on two papermaking pulps, i.e., an average yield softwood unbleached kraft, and the 85-89% yield spruce chemimechanical pulp. Results showed that moderate retentions for some fruit pectins were attained at an addition level of 2% based on fiber. However, when these products were used in handsheets from the same pulps, little or no improvements in strength were attained. Means to enhance the effectiveness of these materials through the use of alum and organic cationic agents are being examined.

In forming fiber/fiber single bonds we had previously experienced difficulty in achieving reproducible results. Only about half (or fewer) attempts produced bonded fibers. We have now developed new techniques which give well-bonded fibers (with close to 90° crossing angle) almost 100% of the time.

We have found that the vertical polarized light technique for measuring bond area does not always give unambiguous results. The problem is incompletely collapsed lumens in some instances. These produce additional scattering in the bond area and make it difficult to determine whether a certain portion of the apparent bond area is indeed bonded. Further work will clarify this.

The influence of pulp yield and degree of refining on bond strength and locus of bond failure will be studied using the new instrumentation developed in Project 3527.

The effect of the chemical additive systems described above on bond strength and locus of bond failure will be studied.

THE INSTITUTE OF PAPER CHEMISTRY

Appleton, Wisconsin

Status Report

to the

PAPER PROPERTIES AND USES

PROJECT ADVISORY COMMITTEE

Project 3469

COMPRESSIVE STRENGTH

April 2-3, 1985

PROJECT SUMMARY

PROJECT TITLE: COMPRESSIVE STRENGTH

PROJECT STAFF: W. J. Whitsitt/J. F. Waterhouse

PROGRAM GOAL:

Date: 3/11/85
Budget: $85,000
Period Ends: 6/30/85
Project No.: 3469

Identify critical parameters which describe converting and end-use performance and promote improvements in cost/performance ratios.

PROJECT OBJECTIVE:

To establish practical methods for enhancing compressive strength during paperboard manufacture.

PROJECT RATIONALE, PREVIOUS ACTIVITY and PLANNED ACTIVITY FOR FISCAL 1985-86 are on the attached 1985-86 Project Form.

SUMMARY OF RESULTS LAST PERIOD: (March 1984 - September 1984)

(1) The effects of high yield pulp substitution on medium performance has been investigated.

(2) The effects of furnish composition variation in the Z direction as medium compressive strength performance has been investigated.

(3) The effects of polymer reinforcement, including location and polymer type on compressive strength is in progress.

(4) The effect of felt type, i.e. commercial felt and blotter on the properties of a medium furnish have been measured.

(5) SEM studies of felt type, i.e. commercial felt and blotter on Formette handsheets has been made.

(6) Preliminary measurements have been made of the effects of forming consistency on compressive strength performance.

SUMMARY OF RESULTS THIS PERIOD: (September 1984 - March 1985)

(1) The effects of cationic starch and cationic starch/PAE combinations on compressive strength and other properties have been investigated.

(2) The effects of inter and intra fiber polymer reinforcement using PVAc via solvent addition on compressive strength and other properties have been investigated.

(3) Further measurements have been made of the effects of handsheet forming conditions at high consistency on compressive strength and other properties.

(4) The effects of press type and drying restraint on sheet anisotropy and other properties have been investigated.

(5) The effect of certain commercial felt types on paper property development has been investigated.

PROJECT TITLE: Compressive Strength

PROJECT STAFF: W. J. Whitsitt/J. F. Waterhouse

PRIMARY AREA OF INDUSTRY NEED: Properties related to end use

PROGRAM AREA: Improved converting processes and converted products

Date: 2/12/85
Budget: $85,000
Period Ends: 6/30/86
Project No.: 3469
Approved by VP-R:

PROGRAM GOAL:

Identify critical parameters which describe converting and end-use performance and promote improvements in cost/performance ratios.

PROJECT OBJECTIVE:

To establish practical methods for enhancing compressive strength during paperboard manufacture.

PROJECT RATIONALE:

Compressive strength is one of the most important end-use properties of linerboard, corrugating medium and other board products. Because of its importance, better ways to improve compressive strength are needed. Changes in Rule 41 being implemented provide impetus for research on compressive strength. However, even in the absence of changes in Rule 41, future fiber and energy needs will encourage changes in board properties to place more emphasis on compressive strength. New research is expanding our knowledge of the compressive response of the board to papermaking processes and the relationship of compressive strength to the elastic stiffnesses governing failure. These developments indicate there are papermaking ways to approach the objective.

RESULTS TO DATE:

We have shown that compressive strength is highly related to the in-plane and out-of-plane elastic stiffnesses of paper. The relationship holds for commercial and experimental sheets made under many conditions. This development enhances opportunities to monitor compressive strength in the mill using ultrasonic techniques and is guiding improvement efforts.

Compressive strength is favored by high densification to increase bonding and high fiber compressive stiffness. Our results on oriented sheets indicate that compressive strength increases with refining but greater increases can be obtained by wet pressing to increase density. Within a practical range higher CD compressive strength can be achieved by decreased fiber orientation and/or increased CD restraint during drying.

PLANNED ACTIVITY FOR THE PERIOD:

We plan to continue investigations of the compressive behavior of board as functions of composition, structure, and process. This includes effects of

fiber properties, pulping, and the effects of papermaking variables; especially wet pressing, wet straining and drying. We will be paying special attention to various types of high yield pulps made from both softwoods and hardwoods and exploratory work is planned to consider use of non cellulosic fibers and special strengthening additives. Practical methods for achieving suitable fiber-to-fiber bonding, sheet formation and directionality will be a necessary part of the work.

An important aspect of the work is the development of information on how the above papermaking factors affect the elastic stiffnesses which govern compressive strength and other properties. This will facilitate on-machine measurement applications.

STUDENT RELATED RESEARCH:

T. Bither, M.S.-1985; P. Ruthven, M.S.-1985

Status Report

COMPRESSIVE STRENGTH

Project 3469

Raw Materials

Consideration has been given to the best means of evaluating the compressive strength potential of high yield pulps (i.e., the range from 70-100%.) In a practical sense it is clear that high yield pulps will require some form of chemical treatment to improve their bonding ability if the expected property losses with increasing yield are to be overcome. However, the treatment may not be selective enough to systematically study only the effects of lignin content; hemicelluloses and other cell wall components also may be removed or modified.

Optimum conditions for fiber separation is another factor to consider with high yield pulps in order to minimize damage to them. Even with a very selective treatment for lignin removal, e.g. acid chlorite treatment, some form of chemical treatment will still be needed to enhance bonding. This problem has been discussed with Chemical Sciences Division personnel and the following approach is viewed as being of mutual interest. To determine compressive strength potential and ease of separation of the fibers as a function of yield, wood coupons will be selectively delignified using an acid chlorite treatment. It is then proposed to characterize the wood coupons using ultrasonic NDT methods.

Polymer Reinforcement

A number of polymeric systems are being investigated with respect to their impact on compressive strength improvement, including PAE/starch, and PVAc in student related work. A series of high, medium, and low viscosity cationic starches have been evaluated both alone and in combination with PAE, using unbleached southern pine unfractionated pulp. When cationic starch is used in combination with PAE, there is an adverse effect on its retention.

In student related work, Paul Ruthven has found significant improvements in compressive strength when interfiber bonds are reinforced with PVAc using solvent addition. Attempts to achieve high levels of intrafiber reinforcement were not altogether successful because of solvent exchange difficulties. At a low level of intrafiber addition, in-plane elastic properties were adversely affected while out-of-plane properties were not. This is attributed to solvent fiber interaction.

PROCESS VARIABLES

Formation

It has been previously demonstrated that as the consistency of formation is increased in the Formette over the range of 0.3 to 2.5%, there is generally a small improvement in properties, whereas with a conventional sheet former (Noble and Woods) there is a marked drop over this consistency range. Formette handsheets have recently been made with and without the usual water wall. In the absence of a water wall the formation of the sheet was drastically effected (as measured by the MKS formation tester). The in-plane elastic properties of the sheet were adversely affected while out-of-plane properties were enhanced. There was still a dramatic loss, however, in both compressive and tensile strength at constant density. In the case of compressive strength, the loss in in-plane modulus was not offset by the gain in Z-direction modulus.

A study was conducted comparing compressive strengths of sheets made in the Noble and Woods former and the Formette at different basis weights (50 g/m^2 - 250 g/m^2) and various wet pressing levels. It was found that variations in compressive strength with basis weight can be accounted for by the variations in elastic properties with basis weight, as judged by the compressive strength and

elastic property correlation developed by Whitsitt. As expected, the correlation does not hold for low basis weight sheets subjected to high levels of wet pressing (where the span/caliper ratio exceeds 7).

Wet Pressing

It has been reported previously that sheet anisotropy decreases with increased levels of wet pressing, refining, and reduction in fiber length. To minimize, this effect, it is important that sheet restraint be maintained through and after wet pressing. This is a condition not readily realized on a paper machine. In a further series of experiments to determine if the above effect is peculiar to our press-dryer combination, one set of Formette sheets were pressed and dried on the belted press-dryer and another set pressed on the Baldwin flat press and subsequently dried on the press dryer combination at zero press load. Various amounts of shrinkage occurred (particularly in the cross machine direction) between the time the sheets were released from the Baldwin Press and the time they were inserted in the press dryer. The shrinkage depended on the furnish (liner and two medium furnishes were investigated) and level of wet pressing. No clear trends in anisotropy were found when the Baldwin Press was used. However, when the elastic properties were extrapolated back to the level of shrinkage which occurred with the press-dryer combination sheets (0.5%), a reduction in sheet anisotropy with increased wet pressing level was again found. Furthermore, the extrapolated elastic properties of the Baldwin pressed sheets were higher than those of the press-dryer combination pressed sheets.

In student related work Tom Bither has continued his investigation of the effects of felt type on paper property development.

THE INSTITUTE OF PAPER CHEMISTRY

Appleton, Wisconsin

Status Report

to the

PAPER PROPERTIES AND USES

PROJECT ADVISORY COMMITTEE

Project 3571

BOARD PROPERTIES AND PERFORMANCE

April 2-3, 1985

PROJECT SUMMARY

Date:	3/11/85
Budget:	$180,000
Period Ends:	6/30/85
Project No:	3571

PROJECT TITLE: BOARD PROPERTIES AND PERFORMANCE

PROJECT STAFF: W. J. Whitsitt/R. A. Halcomb

PROGRAM GOAL:

Develop relationships between critical board property parameters and the way they are achieved as a combination of raw material selection, principles of sheet design and processing.

PROJECT OBJECTIVE:

- To develop relationships between container performance, combined board and component properties.
- To improve the performance/cost ratios of board including medium.
- The short term goals are directed to (1) using structural ECT models to assess the impact of papermaking factors on board performance and (2) improving medium end-use performance properties.

PROJECT RATIONALE, PREVIOUS ACTIVITY and PLANNED ACTIVITY FOR FISCAL 1985-86 are on the attached 1985-86 Project Form.

SUMMARY OF RESULTS LAST PERIOD: (March 1984 - September 1984)

As in the last period our research is focused on corrugating medium improvement and ECT/component relationships.

Section 1 - Medium Improvement

(1) Our results continue to indicate that densification via wet pressing is an effective way to improve forming and strength properties.

(2) Densified mediums give acceptable bonding on the corrugator at high speeds.

(3) Pressing and drying the medium using a linerboard felt contacting the sheet as opposed to blotters gave less dense and rougher sheets which affected some strength properties and water drop. However, both types of medium corrugated satisfactorily.

(4) Densified mediums made with normal and low MD/CD orientation corrugated without fracture or excessive high-lows. A very low density medium did exhibit minor fracture, presumably because of its higher than normal caliper and lower strength properties.

(5) The coefficient of friction of medium decreases with increasing temperature and increases somewhat as moisture content is increased. High friction values increase the risk of flute fracture.

(6) Non-sulfur, green liquor and recycled mediums exhibit different friction values. The low friction coefficient for recycled fiber medium is due to residual waxes on the sheet.

(7) High yield sulfonated chemimechanical medium from red oak appeared to give comparable strength to the semichemical control medium used in past work.

(8) Other work on furnish/sheet structure is in process.

Section 2 - ECT/Component Relations

(1) ECT results are well related to the elastic stiffnesses of the components and STFI tests. The next step in simplification is to substitute elastic stiffnesses for STFI.

(2) For boards made with densified liners and medium the predicted ECT values generally show the same trends as the experimental values.

(3) Satisfactory ECT predictions were also obtained on commercial combined board made from a wide range of liners and medium.

(4) The above results were obtained using an empirical modification of the FPL local buckling model. There are indications we can achieve equally good predictions with a major simplification that, in essence, neglects local buckling.

(5) ECT predictions based on FPL stress-strain curves are fairly accurate but do not always properly predict densification trends.

SUMMARY OF RESULTS OF THIS PERIOD: (October 1984 - March 1985)

Section 1 - Corrugating Medium Improvement and Runnability.

(1) At a constant semichemical hardwood-to-softwood ratio of 75:25 oriented sheets were made as follows: (1) Softwood in outside plies, (2) softwood in center ply and (3) blended control. The results indicated that at constant density.

   a. The highest STFI compressive strength were obtained with the blend and the sheets with softwood outside.

   b. The ECT results of the three furnish constructions were about equivalent.

   c. The blended sheets tended to exhibit the highest flat crush strengths. The sheets with softwood in the inside ply gave somewhat lower flat crush strengths than the blend or the sheets with the softwood in the outer plies.

(2) Additional work on fiber-to-fiber bonding agents is in process.

(3) A part of the FKBG research program on corrugating medium is directed to determining what medium properties are required for high speed runnability, now and in the future. To supplement that research we are considering models to relate critical corrugating speeds to medium properties and certain machine characteristics. As an initial step we are developing a model which relates flute fracture to (a) the frictional and tensile characteristics of the medium (2) nip geometry and (3) brake tension on the corrugator. A similar approach can be used to relate critical speeds for high-low flute formation to medium properties.

(4) The forces imposed in the medium during fluting depend importantly on the flute and roll geometry. Computer models of the nip geometry are being constructed so that the tensile and bending forces on the medium can be estimated and used in our modeling. Initial results indicate that:

a. The wrap angles which affect the tension in the medium vary cyclically during the formation of each flute. This gives rise to tension pulses during the formation of each flute.

b. Our analyses indicates that the medium draw or slippage is completed before the center of the labyrinth. Thus the tension forces reach their maximum before the center of the labyrinth. This is in accord with high speed motion pictures which show that fractures occur about a half-flute before the center.

c. Further analysis of flute and nip geometry should help clarify the effects of flute contour and roll geometry on high speed runnability.

Section 2 - ECT Results

(1) Modification of the FPL local buckling model to incorporate the elastic stiffnesses required empirical fitting of a number of constants, in some cases from limited data. Thus this approach proved to be complex and the results were not always in good agreement with experimental results.

(2) As an alternate a miniature plate model was formulated in two forms. One form utilizes STFI and flexural stiffnesses factors. The other form substituted elastic stiffnesses for the STFI along with the flexural stiffness factors.

a. In general the results indicated that ECT is primarily dependent on the STFI compressive strengths of the liners and medium. The influence of the flexural stiffness term was negligible.

b. In the second form the elastic stiffness terms for the compressive strength were also much more important than the flexural stiffness term. However, the prediction results were less satisfactory in some cases than obtained with the STFI compression results.

PROJECT TITLE: Board Properties and Performance

PROJECT STAFF: W. J. Whitsitt, R. A. Halcomb

PRIMARY AREA OF INDUSTRY NEED: Properties related to end uses.

PROGRAM AREA: Performance and Properties of Paper and Board.

Date: 2/12/85
Budget: $180,000
Period Ends: 6/30/86
Project No: 3571
Approved by VP-R:

PROGRAM GOAL:

Develop relationships between critical paper and board property parameters and how they are achieved in terms of raw material selection, principles of sheet design, and processing conditions.

PROJECT OBJECTIVE:

- To develop relationships between container performance, combined board and component properties.
- To improve the performance/cost ratios of combined board (including medium).
- The short term goals are directed to (1) using structural ECT models to assess the impact of papermaking factors on board performance and (2) improving medium end-use performance properties.

PROJECT RATIONALE:

There are many aspects of box and combined board performance which have not been adequately related to board properties through structurally sound models. Such structural models identify the critical board properties needed for end-use performance. They can then be used to select papermaking approaches to maintain or improve performance at less cost. An important step is to incorporate the elastic stiffnesses of the board into such models. This allows us to use our developing knowledge on how papermaking factors affect the elastic stiffnesses to make board improvements.

RESULTS TO DATE:

Rayleigh-Ritz methods have been used to analyze container failure under several types of load. Finite element techniques have been used to model the bending behavior of container board. Analysis of present ECT vs. component local buckling models indicates they fail to predict ECT performance when the liner or medium density is changed. In the case of medium we have shown that the compressive strength is lowered by high bending and shear stresses imposed during forming. These losses in strength lower flat crush and ECT. The losses are inversely related to the density and Z-direction elastic stiffness of the medium. Densification via wet pressing is one way to improve end-use performance of medium.

PLANNED ACTIVITY FOR THE PERIOD:

The relationships being developed will show how the elastic stiffnesses and compressive strengths of the components will affect combined board ECT. The

analysis will help us assess the relative importance of compressive strength and the bonding stiffnesses of both the liners and medium in determining ECT performance. We will need to confirm and validate the relationships using components made under various papermaking conditions as well as commercial boards.

Our research on medium shows that densification via wet pressing improves strength retention during fluting and gives higher ECT and flat crush in the combined board. We will continue this research and extend it to consider other ways to improve formability and performance. This will include work on sheet structure, the use of additives and pressing variables.

As an outgrowth of this and related work for FKBG we will investigate ways to show what properties of the linerboard and medium are required for high-speed runnability on the corrugator. Runnability refers to the critical speeds associated with strength retention, high-lows and flute fracture.

POTENTIAL FUTURE ACTIVITIES:

Application of similar techniques to end-use failures involving flexure, shear and combined tension, flexure and shear.

Status Report

BOARD PROPERTIES AND PERFORMANCE

Project 3571

The objectives of the program are to: (1) develop relationships between container performance, combined board and component properties and (2) determine ways to improve the cost/performance ratios of linerboard and medium. To fulfill these objectives we must consider both end-use performance and processing runnability on the corrugator.

PROCESS RESEARCH

In the process area, our past work has shown that densification of the medium via wet pressing is an effective way to reduce forming losses. As a consequence such mediums improve the ECT and flat crush strength of corrugated board. We have also begun investigating other ways to improve medium performance, some of which were discussed in the October 1984 status report.

In our current research three furnish structure variations were investigated. For this purpose we made oriented sheets with a constant semichemical hardwood-to-softwood ratio in three ways. They were (1) softwood in outer plies, (2) softwood in inner ply and (3) a blended control. At equal density the results indicated that:

(1) The ECT results for the three furnish constructions were about equivalent.

(2) The blended sheets exhibited the highest flat crush strengths while the sheets with the hardwood outside gave the lowest results.

(3) The compressive strength indexes of the blend and the sheets with softwood outside tended to give slightly higher compressive strengths.

The above work was intended to be exploratory in nature because there are a number of variables such as refining, furnish ratio, and MD/CD variations which

could also be considered. However, the results suggest that there may not be great potentials for improvement by furnish placement. Therefore we are concentrating attention on other ways to improve fiber bonding.

The current trend is to use higher corrugating speeds and we can expect higher target speeds in the future. Higher speeds place increasing demands on the forming characteristics of the medium and bonding process. Concurrent with the speed increases, there are papermaking changes underway which will affect the properties of medium and linerboard. To use our board materials effectively as speeds increase we need to determine what board properties are necessary for high speed runnability. Parts of the FKBG research program in this and succeeding years is directed to this objective.

To supplement the FKBG research we are considering ways to relate critical corrugating speeds for high-lows, flute fracture and strength retention to medium properties. As an initial step a model is being developed which relates flute fracture speeds to (1) the frictional and tensile characteristics of medium (see October 1984 report for data on friction) (2) nip geometry and (3) brake tension on the corrugator. A similar approach probably can be used for high-lows.

The proposed model predicts that the critical speed increases with increasing tensile strength and decreasing coefficient of friction and brake tension. The speed is particularly sensitive to the friction coefficient. These trends are in agreement with known facts. As we improve and expand the model to include other stress effects, it will provide a powerful tool for identifying the critical medium properties.

This research has indicated that we need more information about the nip geometry. We have taken casts of our C-flute roll and are analyzing the contours mathematically to determine the wrap angles of the medium. The wrap angles affect the tension in the labyrinth while the tip radius affects the bending strain. The computer analysis of the nip geometry will help assess profile effects on high speed runnability.

Our initial work indicates that the wrap angles and hence the tension on the medium varies cyclically during the formation of each flute. This can give rise to tension pulses which may explain speed effects. Our computer analysis indicates that the slippage of the medium over the tips is complete before the center of the nip. This would explain why fractures occur about a half flute before center of the nip.

ECT RESEARCH

Several attempts were made to adapt the FPL local buckling model to incorporate the elastic stiffnesses as had previously been done for STFI. The most successful of these attempts required using four adaptive constants which made this approach unsatisfactory.

Another approach to analyzing combined board ECT is to treat the problem in the same way as the Institute top load box compression formula - i.e., the maximum strength of the individual liner and medium plate elements is dependent upon the elements edgewise compressive strength and its elastic buckling characteristics. Following this approach the liner contribution to ECT is formulated as the product of two terms:

$$\left[\begin{array}{l}\text{compressive strength}\\ \text{of the liner}\end{array}\right]^{b} \cdot \left[\begin{array}{l}\text{geometric mean}\\ \text{flexural stiffness}\\ \text{of liner}\end{array}\right]^{1-b}$$

and the medium's contribution is formulated similarly as

$$\left[\begin{array}{l}\text{compressive strength}\\ \text{of the medium}\end{array}\right]^{c} \cdot \left[\begin{array}{l}\text{geometric mean}\\ \text{flexural stiffness}\\ \text{of medium}\end{array}\right]^{1-c}$$

where b and c are constants to be experimentally determined. The combined board ECT prediction is then the sum, with the appropriate multiplicative factors, of these two expressions plus an additive constant. This approach was investigated to two forms: (1) using STFI as the measure of the components compressive strength and (2) using $(E_y t^{0.75} E_z t^{0.25})$ as the measure of the components compressive strength. In both forms the flexural stiffnesses were estimated from elastic stiffness measurements. When the STFI values were used with a set of 85 commercial boards made from various component grades, the constants b and c were not found to differ significantly from 1.0. Thus the flexural stiffness terms seemed to have no effect on ECT. This result should be validated by using sheets with varying ratios of STFI compression strength to flexural stiffness. The average predictive accuracy for the 85 boards was about 3.7%. When this STFI form was applied to a set of 23 experimental boards using the regression constants determined from the set of 85 commercial boards, the average predictive accuracy was 6.9%.

In the alternative form using $(E_y t^{0.75} E_z t^{0.25})$ in place of STFI as the measure of component compressive strength, the empirically determined values for b and c for the set of 85 commercial boards were 0.87 and 1.0, respectively. These values indicated that the flexural stiffness term for the liners has a small effect on ECT while the medium's flexural stiffness term has no effect. The average predictive accuracy for the 85 boards was about 3.6%. When this form was applied to the set of 23 experimental boards using the regression

constants determined from the set of 85 commercial boards, the average predictive accuracy fell to 15.1%. While this level of agreement is not satisfactory, it was noted that the ECT trends in the series of board made with densified components were correctly predicted.

THE INSTITUTE OF PAPER CHEMISTRY

Appleton, Wisconsin

Status Report

to the

PAPER PROPERTIES AND USES

PROJECT ADVISORY COMMITTEE

Project 3500

COMBINED STRESS AND FAILURE PROCESSES

April 2-3, 1985

PROJECT SUMMARY

Date: 3/11/85
Budget: $70,000
Period Ends: 6/30/85
Project No: 3500

PROJECT TITLE: Combined Stress and Failure Processes (Formerly Shear Deformation and Failure)

PROJECT STAFF: J. F. Waterhouse

PROGRAM GOAL:

Develop relationships between the critical paper and board property parameters and how they are achieved in terms of raw material selection, principles of sheet design, and processing conditions.

PROJECT OBJECTIVE:

The objective is to improve methods for evaluating the in-plane and out-of-plane deformation behavior of paper and to relate these to end use performance, sheet composition and structure.

PROJECT RATIONALE, PREVIOUS ACTIVITY and PLANNED ACTIVITY FOR FISCAL 1985-86 are on the attached 1985-86 Project Form.

SUMMARY OF RESULTS LAST PERIOD: (March 1984 - September 1984)

(1) A preliminary analysis has been developed for calculating the variation of in-plane internal stresses in the Z direction of paper and board.

(2) The variation of properties in the Z direction have been measured on high temperature press-dried handsheets.

(3) A review paper on the "Ultimate Strength of Paper" has been prepared and presented at the Progress in Paper Physics Meeting, Stockholm, Sweden, June 1984.

SUMMARY OF RESULTS THIS PERIOD (September 1984 - March 1985)

(1) The effect of the severity of surface grinding on the measurment of in-plane and out-of-plane properties has been investigated.

(2) A brief investigation of the relationship of formation (MKS Formation Tester) and other sheet variables to tensile strength of commercial liner-board and medium has been made.

(3) An investigation of the effects of supercalendering on strength and other properties of coated and uncoated papers is in progress.

(4) The Hertel laboratory calender and supercalender has been relocated and is once again operational.

(5) A seminar on "Paper Properties, Terminology and Effects on Web Control" was given at a meeting organized by Rockwell International on Printing Press Web Control, February 19, 1985, Chicago.

PROJECT TITLE: Combined Stress and Failure Processes (Formerly Shear Deformation and Failure)

PROJECT STAFF: J. F. Waterhouse

PRIMARY AREA OF INDUSTRY NEED: Properties related to end uses

PROGRAM AREA: Performance and properties of paper and board

Date: 2/12/85
Budget: $70,000
Period Ends: 6/30/86
Project No: 3500
Approved by V-R:

PROGRAM GOAL:

Develop relationships between critical paper and board property parameters and how they are achieved in terms of raw material selection, principles of sheet design, and processing conditions.

PROJECT OBJECTIVE:

The objective is to improve methods for evaluating the in-plane and out-of-plane deformation behavior of paper and to relate these to end use performance, sheet composition and structure.

PROJECT RATIONALE:

We believe that both in-plane and out-of-plane properties are important to such converting processes as corrugating, molding, creasing, scoring and other forms of out-of-plane shape modification. Many converting operations involve combined in-plane and out-of-plane stresses (e.g., shear and bending) beyond the elastic regime and successful converting will depend on the sheet's ability to withstand these stresses. Research is needed to identify these critical stresses and the mechanism of failure. We wish to understand how the choice and location of materials in the web and the papermaking process affects properties, and to what extent they can be controlled to enhance the paper or boards converting characteristics, i.e., runnability and post conversion properties.

RESULTS TO DATE:

Investigated methods for measuring the stress-strain behavior in out-of-plane shear. Developed torsion mode technique for measuring shear. Studied effect of shear straining on compressive strength. Internal stress variations have been determined in the thickness direction of paper together with the variation of in-plane and out-of-plane properties. A study has also been made on the effects of surface grinding variables on both in-plane and out-of-plane property measurements.

PLANNED ACTIVITY FOR THE PERIOD:

1) Explore possible methods for measuring combined stress deformation behavior.

2) Determine the effect of raw material and process variables on both in-plane and out-of-plane properties in the thickness direction of paper.

STUDENT RELATED RESEARCH: L. Charles, M.S.-1986

Status Report

COMBINED STRESS AND FAILURE PROCESSES

Project 3500

Project Title Change

Combined Stress and Failure Processes. The title of this project has once again been changed in order to more adequately reflect the work which is being undertaken and its broader base of activity. Specifically it seemed desirable to avoid the the connotation that the failure of interest was only associated with shear deformation as was implied by the former project title, "Shear Deformation and Failure".

Internal Stress and Variation of Properties in the Thickness Direction of Paper

Significant variations in both in-plane and out-of-plane elastic properties have been measured in the thickness direction of paper using surface grinding techniques. In addition to seeking alternative methods of material removal (e.g. ion milling or laser machining) the impact of grinding severity on property measurements has also been investigated. Samples of commercial linerboard were characterized by measuring the in-plane and out-of-plane elastic properties prior to surface grinding. Material was removed by grinding at the following levels 3.5 mils x 2 passes, 1.75 mils x 4 passes, and 0.5 mils x 14 passes. Wire, felt, and middle sections of the board were obtained using the above three grinding levels. After reconditioning at 50% RH and 23°C, the samples were again characterized and curvature measurements were made on the samples.

Formation

Sheet formation is important with respect to its impact on the visual or aesthetic characteristics of paper, as well as strength related properties in

converting and end-use applications. It is the latter contribution we are concerned with here. We recently had the opportunity to make a limited evaluation of the MK systems Optical Formation tester. Samples of 26-lb medium and 42-lb linerboard were chosen together with two Formette handsheets which had "good" and "bad" formation (the instrument did verify this finding). The sheets were first characterized by measuring in-plane and out-of-plane elastic properties and then tensile strength measurements were made. A stepwise regression analysis was made between geometric mean tensile strength and the following independent variables: in-plane geometric mean specific stiffness, longitudinal out-of-plane specific stiffness, sheet apparent density, and MK Formation Number. A high degree of correlation was found between tensile strength and in-plane stiffness for both medium and liner samples followed by MK formation number and longitudinal out-of-plane stiffness. The Formette handsheets samples did not fit the commercial linerboard correlation.

Supercalendering

Supercalendering is an important converting process which mainly serves to enhance the surface characteristics of paper and board, i.e. smoothness and gloss control. In student related work, Laurine Charles will be attempting to understand how supercalendering affects strength related properties of both coated and uncoated papers. It is generally known that supercalendering can have both a beneficial and an adverse effect on strength properties. We wish to understand how the beneficial effects may be maximized and the adverse effects eliminated or minimized.

THE INSTITUTE OF PAPER CHEMISTRY

Appleton, Wisconsin

Status Report

to the

PAPER PROPERTIES AND USES

PROJECT ADVISORY COMMITTEE

Project 3467

PROCESS, PROPERTIES, PRODUCT RELATIONSHIPS

April 2-3, 1985

PROJECT SUMMARY

PROJECT TITLE: PROCESS, PROPERTIES, PRODUCT RELATIONSHIPS

PROJECT STAFF: G. A. Baum/ C. C. Habeger

PROGRAM GOAL:

Date: 3/11/85
Budget: $105,000
Period Ends: 6/30/85
Project No: 3467

Develop relationships between critical paper and board property parameters and the way they are achieved as a combination of raw material selection, principles of sheet design and processing.

PROJECT OBJECTIVE:

To improve our capability of mechanically characterizing paper and board materials.

To relate measured parameters to end-use performance (especially in the case of Z-direction measurements).

To relate measured parameters to machine and process variables.

PROJECT RATIONALE, PREVIOUS ACTIVITY and PLANNED ACTIVITY FOR FISCAL 1985-86 are on the attached 1985-86 Project Form.

SUMMARY OF RESULTS LAST PERIOD: (March 1984 - September 1984)

1. The effects of beating time, degree of delignification, fiber orientation, and wet pressing pressure on the elastic properties of paper made from red oak were studied in student research (B. Berger). Although the analyses are not complete, the results to date are presented in the Section 1, PAC Status Reports, October, 1984.

2. Differences between rubber platen and hard platen caliper values have been assumed to be a measure of paper "roughness". This idea has been tested by comparing such differences with values of surface smoothness measured by conventional means. The results indicate that the rubber platen gage, together with a standard caliper gage, can give a good measure of paper roughness. This is described in attached Section 2, PAC Status Reports, October, 1984.

3. The automation of the system for measuring in-plane elastic properties of paper is nearing completion. The hardware and electronics are essentially complete, but there still is quite a lot of software to be written (as of this writing). A brief description of the system is given in Section 3, PAC Status Reports, October, 1984.

4. The laboratory system for measuring out-of-plane elastic parameters still requires a lot of operator time for each measurement. Automation of these two gages (longitudinal and shear) is now underway. This will speed up the measurements and reduce operator error. A brief description is given in Section 4, PAC Status Reports, October, 1984.

5. Previous work at IPC demonstrated that dielectric measurements in paper could reveal information about fiber alignment. We have initiated an effort to use this fact to construct a fiber orientation gage for use in the laboratory. A brief description of the proposed system is given in Section 5, PAC Status Reports, October, 1984.

6. A paper titled "The Elastic Properties of Paper - A Review" was presented at the Paper Physics Seminar in June. This is IPC Technical Paper No. 145, a copy of which is included as Section 5, PAC Status Reports, October, 1984.

SUMMARY OF RESULTS THIS PERIOD: (October 1984 - March 1985)

1. The importance of wet pressing, refining, and yield on ZD elastic properties has been studied and a paper written for publication. The paper will be available at the April PAC meeting.

2. The effects of pulp mill and paper mill process variables on Poisson ratios and C_{12} have been re-examined. The mean of the Poisson ratios decreased with increasing density.

3. A microwave device for measuring the level of fiber orientation in a sheet has been constructed and is currently being tested.

4. The robotic or automatic device for measuring paper in-plane elastic properties has been improved in several ways. The sampling area has been relocated to be in the center portion of the specimen and software written to allow measurements of in-plane properties at various angular displacements from the MD (in 5° steps).

5. Equipment has been acquired to decrease the measurement time for the out-of-plane elastic property measurements. Work is underway to automate this system.

PROJECT TITLE: Process, Properties, Product Relationships

PROJECT STAFF: G. A. Baum

PRIMARY AREA OF INDUSTRY NEED: Properties related to end uses

PROGRAM AREA: Performance and Properties of Paper and Board

Date: 2/12/85

Budget: $105,000

Period Ends: 6/30/86

Project No: 3467

Approved by VP-R:

PROGRAM GOAL:

Develop relationships between the critical paper and board property parameters and how they are achieved in terms of raw material selection, principles of sheet design, and processing conditions.

PROJECT OBJECTIVE:

To improve our capability of characterizing paper and board materials.

To relate measured parameters to end-use performance (especially in the case of Z-direction measurements).

To relate measured parameters to machine and process variables.

PROJECT RATIONALE:

It is important to understand the relationships between end-use performance and properties in order to improve paper and board products or maintain performance within close tolerances while effectively utilizing available raw materials, minimizing energy requirements, and minimizing environmental impacts.

RESULTS TO DATE:

Ultrasonic techniques for measuring in-plane and out-of-plane elastic properties of paper have been developed. A caliper gage has been designed and constructed to allow simultaneous measurement of caliper and Z-direction ultrasonic measurements. This caliper gage has been evaluated and found to be comparable or superior to other methods of accurately measuring caliper. The effects of fiber orientation, wet pressing, wet straining and drying restraints on the in-plane and out-of-plane properties of paper have been studied. The in-plane and out-of-plane elastic parameters have been related to end use tests and converting performance in a number of cases.

PLANNED ACTIVITY FOR THE PERIOD:

1. In-plane and out-of-plane elastic constants will be measured on a representative group of samples differing in composition and structure and in different ambient environments. These data will be compared with use-oriented test results, where possible. Particular attention will be given to the effects of yield and refining level on ZD properties.

2. Specific scattering coefficients will be measured in heavy board materials differing in composition and structure. These will be used to predict relative bonded area.

3. Work on ZD velocity measurements in thin and rough samples will continue. Improvements in the existing apparatus are anticipated.

4. The effort to establish relationships between properties and end-use performance will continue.

5. Completion of a new automated laboratory device for measuring in-plane parameters that will be operator "friendly and fool proof".

STUDENT RELATED RESEARCH:

M. Forbes, Ph.D.-1985; B. Pankonin, Ph.D.-1985; B. Berger, Ph.D.-1987; B. Berger, M.S.-1984; D. Waterman, M.S.-1986; W. Westerveldt, M.S.-1986.

Status Report

PROCESS, PROPERTIES, PRODUCT RELATIONSHIPS

Project 3467

There has been quite a lot of activity related to this project during the past time period (October 1984 - March 1985). The work may be separated into two general categories. The first involves instrumentation or hardware development and the second concerns laboratory work and interpretation relative to the effects of wet pressing, refining, and yield on elastic properties and relationships between elastic properties.

The prototype of the automatic system for measuring the in-plane elastic properties of paper has been completed and tested with good results. Several minor modifications have been made which improve on the measurements. Experience to date suggests that the device is an improvement over the manual measurements in that the standard deviation of the results tends to be less for the automatic (robotic) system. The measurement time is about the same, but of course the robotic system runs unattended. In addition, software has been written which allows measurements of the in-plane properties at angular displacements (in 5 degree steps) from the MD. The resulting polar graphs provide information about the distribution of fibers in the plane of the paper.

Work is underway to shorten the time required for measuring the out-of-plane elastic properties. At present, these tests are quite time consuming since they require extensive operator interaction. By automating certain parts of the test procedure, the operator involvement can be decreased with a concomitant decrease in the time required for each test. This is quite important since the requests for these tests from industry has grown to the point where it is difficult to keep up with the demand.

In previous discussions we have mentioned the possibility of monitoring the degree of fiber orientation in the plane of paper by monitoring the microwave dielectric constants in the MD and CD directions. The dielectric constants are insensitive to drying restraints and hence should be uniquely related to fibrillar orientation and thus fiber orientation in the paper. We have assembled an apparatus which should enable us to demonstrate this.

The elastic properties of paper are very sensitive to paper machine operating variables such as fiber orientation, wet pressing, wet straining, and drying restraints. Studies of these interactions and relationships between elastic properties have been conducted under this project. More recently we have begun to study the effects of yield and refining on the elastic properties and the relationships between properties. Work to date indicates that these mill variables, together with wet pressing, are extremely important in controlling the ZD elastic properties and related strength properties. This activity will be continued in the near future.

As a part of the above effort, the importance of Poisson ratios have been re-examined. In our original work on commercial papers the geometric mean of the in-plane Poisson ratios was found to be relatively insensitive to changes in sheet density. In many of the experimental papers we have been studying, however, this does not appear to be the case. The geometric mean decreases with increasing density. The effects of paper machine operating variables on the Poisson ratios and C_{12} are thus being reconsidered.

G. A. Baum
3/11/85

THE INSTITUTE OF PAPER CHEMISTRY

Appleton, Wisconsin

Status Report

to the

PAPER PROPERTIES AND USES

PROJECT ADVISORY COMMITTEE

Project 3332

ON-LINE MEASUREMENT OF PAPER MECHANICAL PROPERTIES

April 2-3, 1985

PROJECT SUMMARY

Date:	3/11/85
Budget:	$75,000
Period ends:	6/30/85
Project No.:	3332

PROJECT TITLE: ON-LINE MEASUREMENT OF PAPER MECHANICAL PROPERTIES

PROJECT STAFF: G. A. Baum/C. C. Habeger

PROGRAM GOAL:

Develop ways to measure and control manufacturing processes.

PROJECT OBJECTIVE:

To develop the capability to measure certain elastic parameters on a moving paper web. Current emphasis is on in-plane measurements on low basis weight papers and on out-of-plane measurements.

PROJECT RATIONALE, PREVIOUS ACTIVITY and PLANNED ACTIVITY FOR FISCAL 1985-86 are on the attached 1985-86 Project Form.

SUMMARY OF RESULTS LAST PERIOD: (April 1984 - September 1984)

1. It has been shown that the on-line sensor can detect changes in web properties due to machine upsets.

2. Changes in machine operating variables produce predictable changes in web properties. The effects of refining, rush-drag ratios, draws, wet pressing pressure, and consistency were studied.

3. The on-line sensor can be used to obtain CD profiles of mechanical properties.

SUMMARY OF RESULTS THIS PERIOD: (October 1984 - March 1985)

1. A comprehensive report covering the work for FKBG (the Owens-Illinois-Valdosta sensor) has been written.

2. The DOE proposal concerned with on-machine measurements (both in-plane and out-of-plane) is now expected to be funded before June, 1985.

3. The automated in-plane laboratory system is completed except for a cover. It is discussed in the Project 3467 Status Report.

4. Equipment to measure mechanical properties as functions of temperature and moisture is under construction. This will be used for fundamental research and also used for obtaining calibration curves for on-machine sensors.

PROJECT TITLE: On-Line Measurement of Paper Mechanical Properties

PROJECT STAFF: G. A. Baum/C. C. Habeger

PRIMARY AREA OF INDUSTRY NEED: Properties related to end uses

PROGRAM AREA: Control of manufacturing processes

Date: 2/12/85
Budget: $75,000
Period ends: 6/30/86
Project No.: 3332
Approved by VP-R:

PROGRAM GOAL: Develop ways to measure and control manufacturing processes

PROJECT OBJECTIVE:

To develop the capability to measure certain elastic parameters on a moving paper web. Current emphasis is on in-plane measurements on low basis weight papers and on out-of-plane measurements.

PROJECT RATIONALE:

The ability to measure certain mechanical properties on the paper machine is valuable from several standpoints. It provides a potential means for control of process variables. It provides a non-destructive way to assess product quality on a continuous basis, since certain mechanical properties are correlated with common paper specifications.

RESULTS TO DATE:

Developed theory of ultrasound propagation in paper and developed device for measuring paper and board in-plane elastic parameters on-machine. Successfully tested device in mill environment. Constructed rugged version for extended testing in linerboard mill (contract research). Constructed and tested a version useful for light weight grades which is also self calibrating. Most recently developed cross correlation technique for use with in-plane velocity measurements, and initiated work relating to on-line measurements of z-direction properties. Designed, built, and tested a robotic instrument for measuring in-plane velocities in paper.

PLANNED ACTIVITY FOR THE PERIOD:

We intend to continue studies to explore the possibility of making out-of-plane ultrasonic measurements on a moving paper web. We will try to develop high frequency, broad banded, and low impedance transducers for acoustic coupling to paper in the z-direction. We plan to look at both ceramic and plastic piezoelectric transducer constructions. Hardware and software for a high speed data acquisition system will be designed and built. On-line caliper measurements techniques will be investigated.

POTENTIAL FUTURE ACTIVITIES:

A proposal has been submitted to the Department of Energy to investigate possible control strategies on the paper machine, and to develop a sensor to measure out-of-plane properties.

Status Report

ON-LINE MEASUREMENT OF PAPER MECHANICAL PROPERTIES

Project 3332

Activity during the last time period includes the preparation of a comprehensive report covering the work in Valdosta, a summary paper for publication, and preliminary work concerned with moisture and temperature effects in paper.

Concerning the latter item, we are constructing an ultrasonic velocity gage in a temperature-humidity controlled oven, so that we can conduct fundamental studies of the mechanical properties paper and provide (as a service) moisture-temperature correction formulae for on-line velocity gages. We have procurred and tested a Blue M oven capable of giving the proper ranges of temperature and moisture. Transducers which can withstand the 100°C temperature extreme have been constructed. A digital thermometer and a digital balance have been purchased to monitor temperature and moisture. Design and construction of the transducer mounting apparatus is underway. We still must interface the temperature and moisture transducers with the computer and write the software necessary to automate the data acquisition.