Short Span Compression Test (SCT) Variation – Control and Management

Roman Popil, September 2012

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500 10th St NW, Atlanta GA.

SCT is Replacing RCT

Ring Crush specimen after testing; buckling and rolling edges clearly visible

Photo: Mike Schaepe, IPST

SCT is replacing RCT

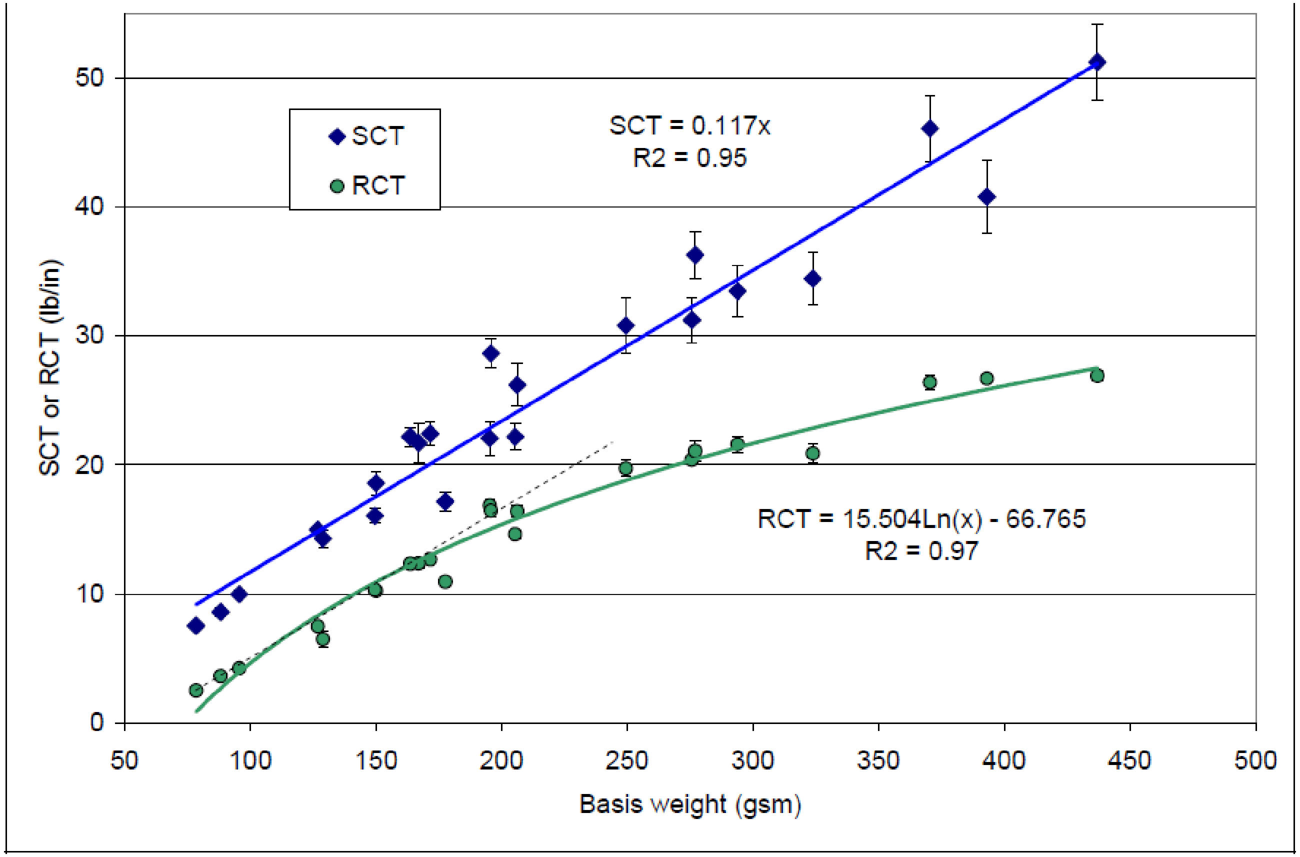


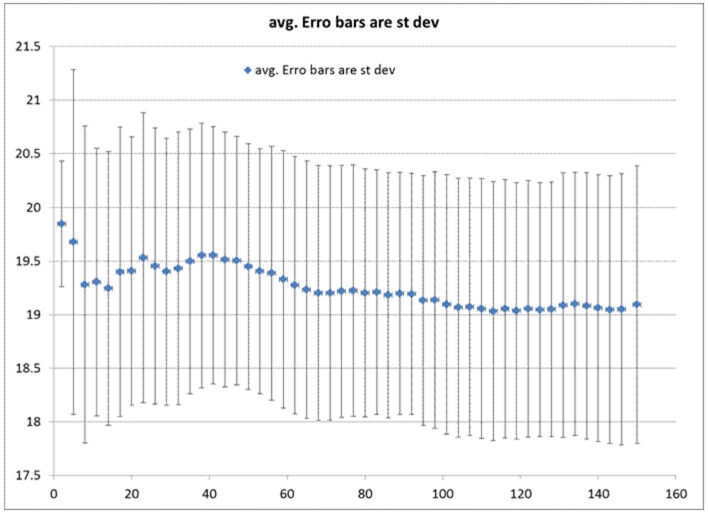
Figure 4. Comparison of SCT and RCT with basis weight of samples.

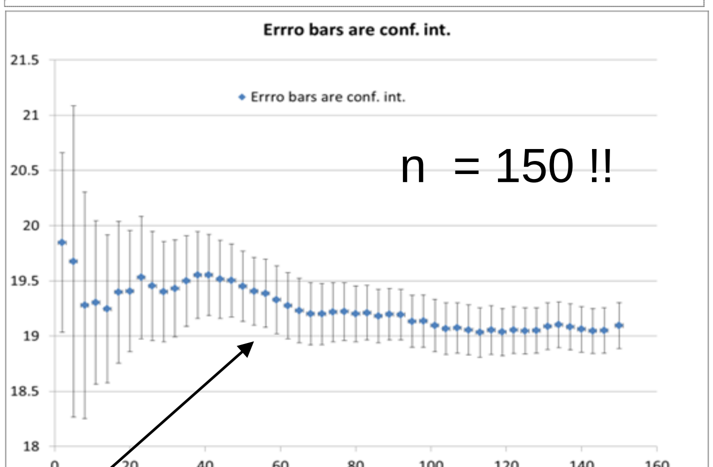
SCT tracks basis weight, RCT does not and is ~1/2 SCT, SCT does not have bending but…higher variation than RCT

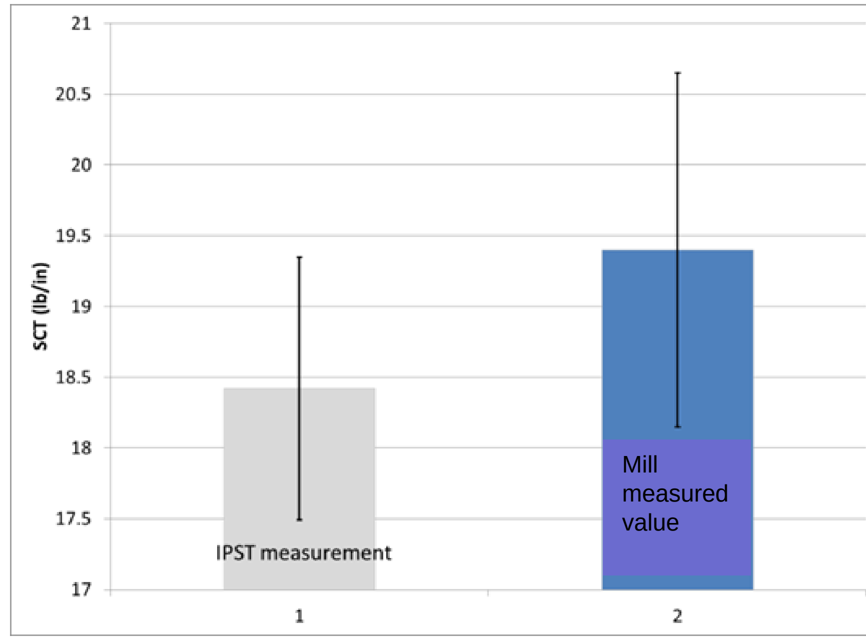
23 southeast linerboards and medium, from Popil, Tappi PaperCon 2010

Measuring SCT on the same sample on 2 different labs, an example, IPST Paper Analysis lab data

A Northeastern mill measured the same sample 150 times to improve accuracy







18.42 ± 0.93 (5%)
@IPST

19.41 ± 1.25 (6.4%)
at mill

Error bars in c.i. ***decrease*** as 1/√n, Tappi standard is n = 10

Overlapping error bars (for n=20 here) indicate ***no*** significant difference

R&R data: 2 instruments, same MD position, 3 operators

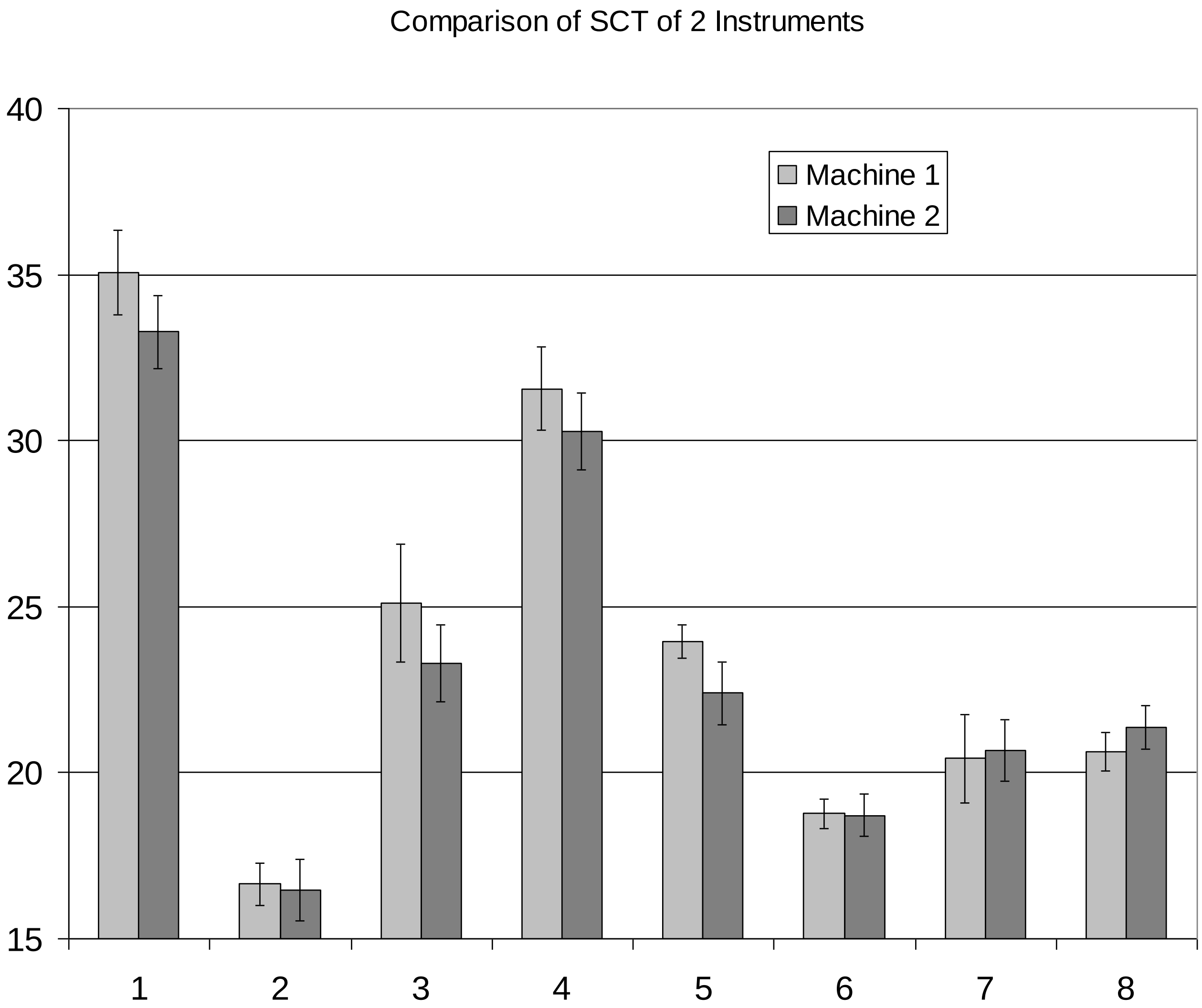
Descriptive Statistics: STFI Primary

Instrument 1

Variable	Sample	Total Count	Mean	StDev	CoefVar	Range
STFI Primary	S-1	9	35.067	1.946	5.55	6.200
	S-2	9	16.656	0.974	5.85	3.300
	S-3	9	25.100	2.700	10.76	9.300
	S-4	9	31.567	1.912	6.06	6.500
	S-5	9	23.944	0.752	3.14	2.400
	S-6	9	18.778	0.680	3.62	2.300
	S-7	9	20.422	2.031	9.94	6.500
	S-8	9	20.644	0.883	4.28	2.500

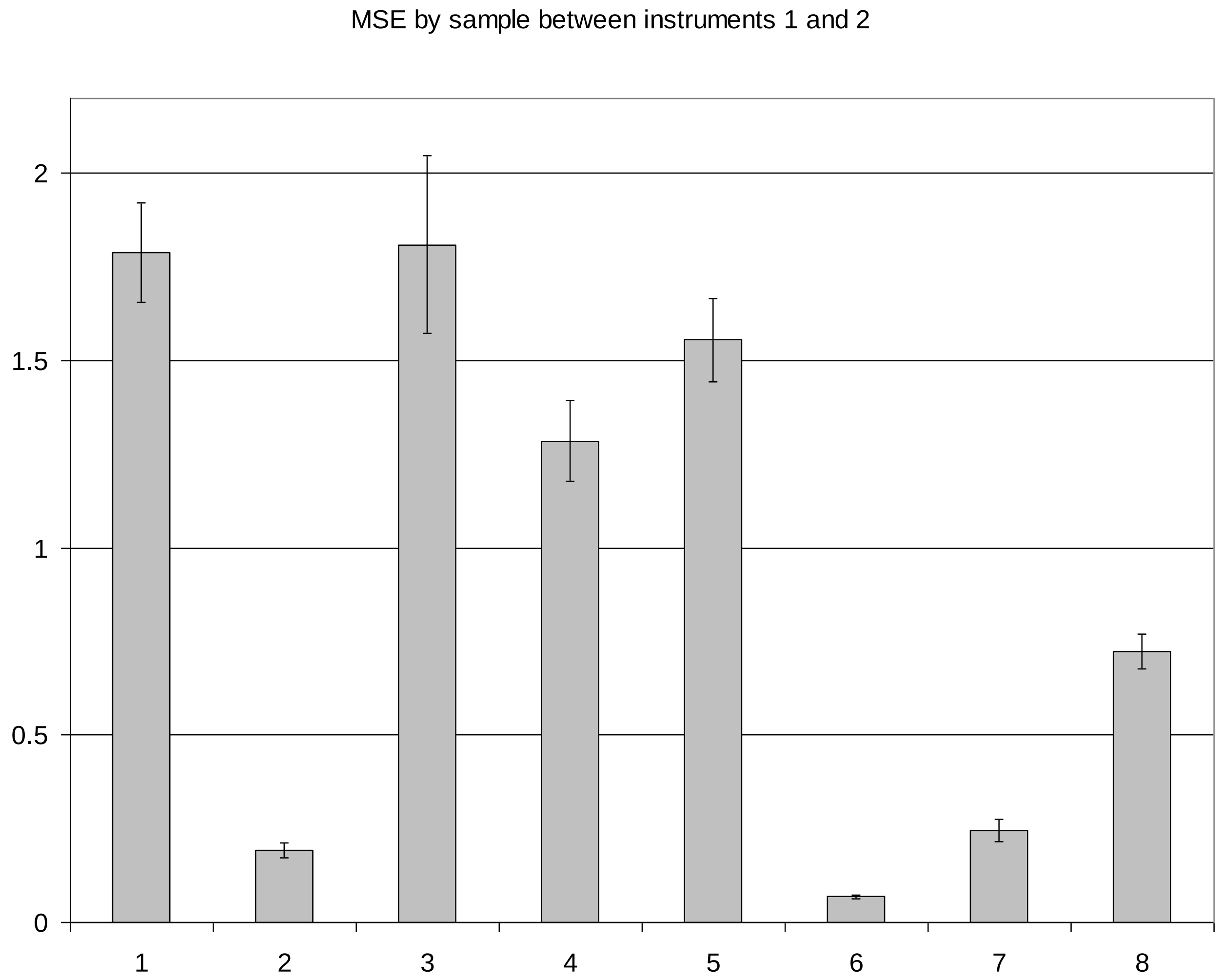
Instrument 2

Variable	Sample	Total Count	Mean	StDev	CoefVar	Range
STFI Backup	S-1	9	33.279	1.671	5.02	5.200
	S-2	9	16.463	1.436	8.72	4.300
	S-3	9	23.291	1.757	7.55	5.900
	S-4	9	30.282	1.760	5.81	4.600
	S-5	9	22.389	1.419	6.34	4.700
	S-6	9	18.708	0.973	5.20	3.000
	S-7	9	20.667	1.416	6.85	3.500
	S-8	9	21.367	1.009	4.72	3.400



Average **repeatability** is the average of the errors divided by the respective average values = ~ 4% for both instruments for 8 different samples

Error bars are 95% confidence intervals, overlapping bars indicate no significant differences between the 2 machines



Reproducibility is the relative % difference (difference in the sample mean/mean) for each 1- 8 samples for both machines. The average difference in values between the 2 instruments is 3.7%

Absolute value of the difference in mean values by sample between the 2 instruments, looks like sample 3 gave the highest variation calculated by the summation in quadrature of the errors

R&R – by simple spreadsheet calculations

3 confidence interval c.i.

2 standard deviation

1 mean

4 confidence interval/mean value

absolute value of the difference between mean readings per sample

relative disagreement between the 2 machines per sample sqrt(delta)/avg(mean 1,mean2) x 100%

Sample	mean 1	std dev 1	c.i. 1	c.i.1/mean	mean 2	std dev 2	c.i.2	c.i. 2/mean 2	sqrt(delta)	error	% delta
1	35.067	1.946	1.271	3.626	33.279	1.671	1.0916999	3.280	1.788	0.134	5.232
2	16.656	0.974	0.636	3.820	16.463	1.436	0.938	5.699	0.193	0.020	1.165
3	25.1	2.7	1.764	7.028	23.291	1.757	1.148	4.928	1.809	0.238	7.477
4	31.567	1.912	1.249	3.957	30.282	1.76	1.150	3.797	1.285	0.108	4.155
5	23.944	0.752	0.491	2.052	22.389	1.419	0.927	4.141	1.555	0.110	6.712
6	18.778	0.68	0.444	2.366	18.709	0.973	0.636	3.398	0.069	0.004	0.368
7	20.422	2.031	1.327	6.497	20.667	1.416	0.925	4.476	0.245	0.030	1.193
8	20.644	0.883	0.577	2.794	21.367	1.009	0.659	3.085	0.723	0.046	3.442

mean repeatability % **4.018** **4.101**

mean reproducibility **3.718**

gauge r&r % **5.499**

5 mean of relative confidence interval for 8

This means that SCT = mean value +/- 4% for results from one machine using this sampling method (all samples contiguous and within same slice position on reel)

square root of the sums of squares of repeatabilityand reproducibility

reproducibility is the average relative disageement between the 2 machines

R&R in this case means that differences of less than 5% between the mean values obtained by the 2 machines are insignificant

Sources of variation - formation

160 mm

15
mm

Strip width is about 2 flocs wide

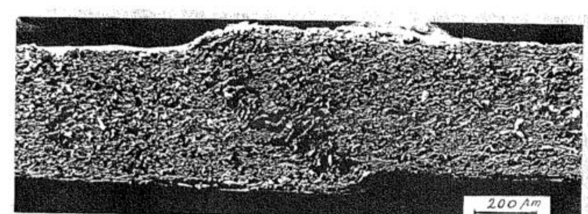
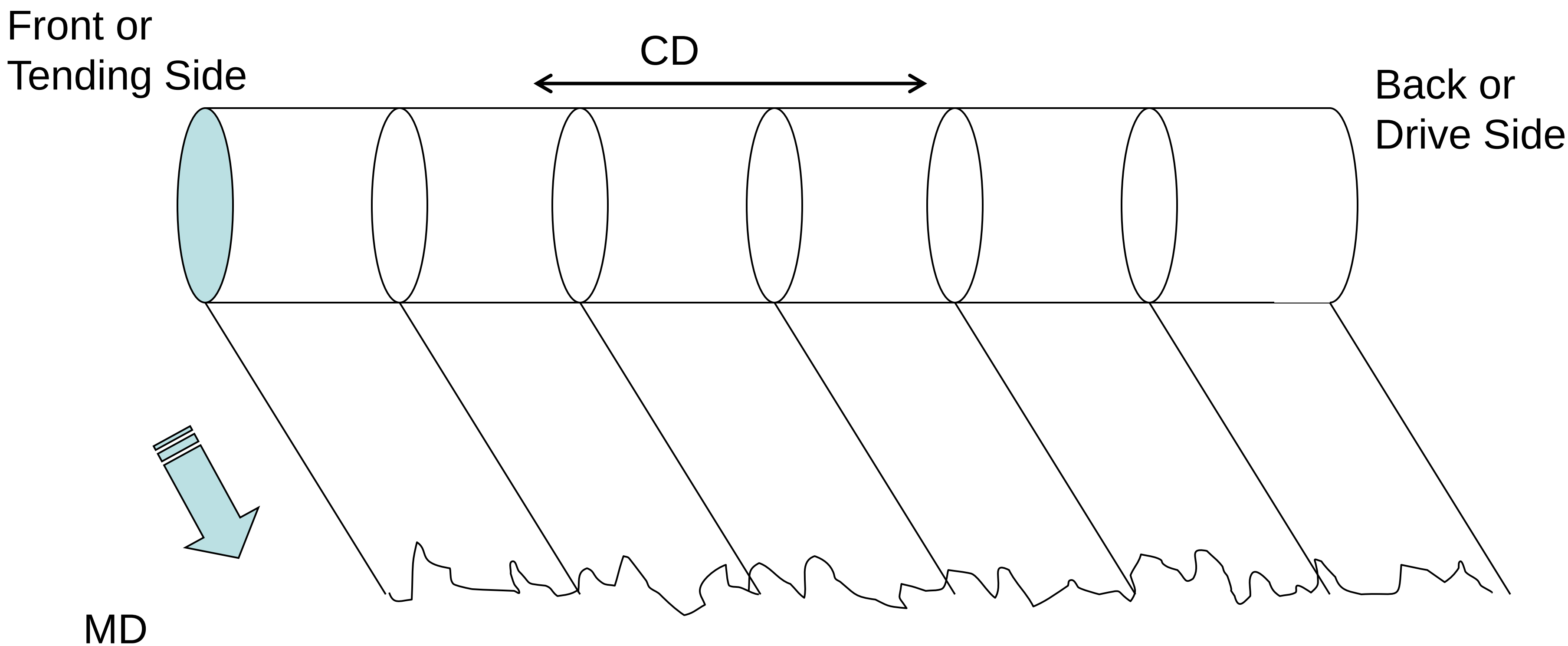


Figure 10. Paperboard specimen after compressive failure[18].

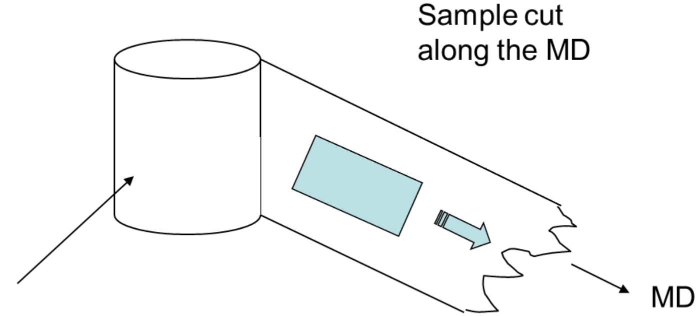
SCT tests a length only 0.7 mm long across 1 -2.5 flocs along the strip length.

Mass formation cv% 6 – 8% , SCT is proportional to mass, mass is proportional to modulus, therefore **variation is inevitable** !!

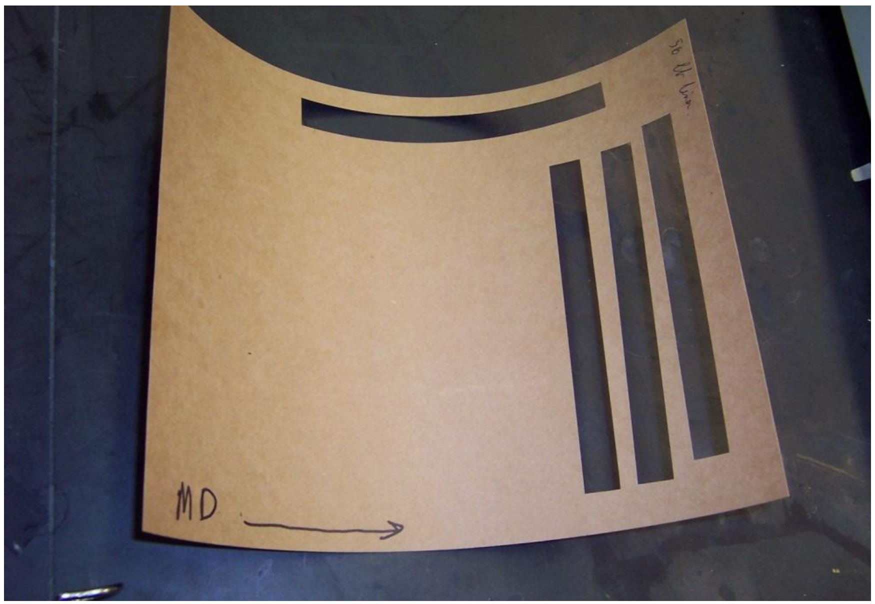
Effect of MD and CD position sampling

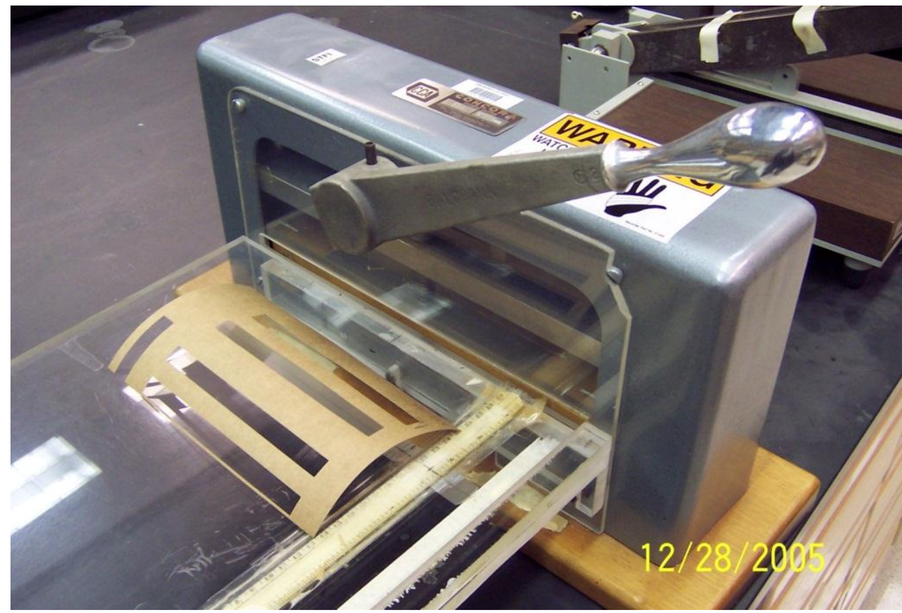


Paper from a paper machine has a variation in the MD and the CD, CD variation arises from drying profiles, headbox edge flows, MD are high frequency variations, flocs, wire marks, etc.

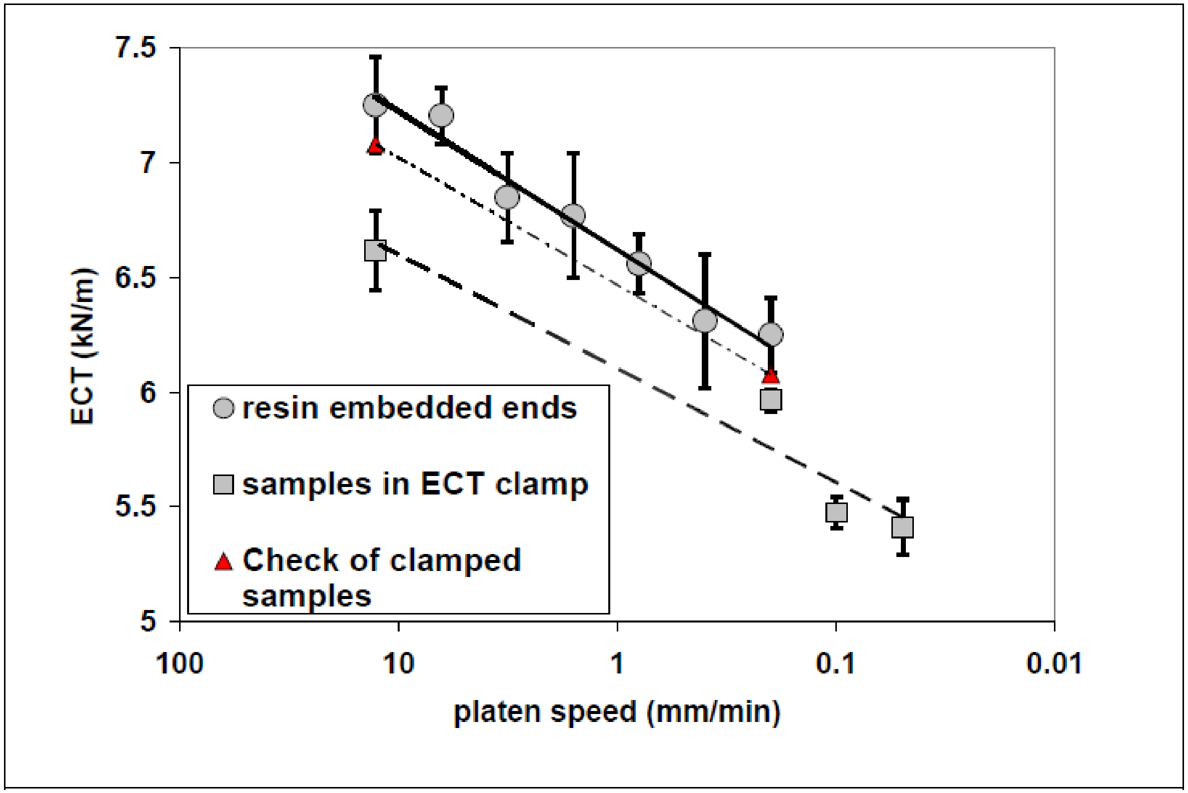


Cutting strips with a punch cutter at the same MD position contiguously should reduce sample variability.





Other effects - speed



$$\frac{ECT}{ECT_{(Tappi)}}(\%) = 3.11 \times \ln(v) + 91.7 \pm 0.4$$

A factor of 10 change in speed causes a 6 % change in compression strength in ECT, from *Popil, Bioresources Journal 2012*

L&W Calibration service ("PMA") check

Lorentzen & Wettre

Instrument Detail: SE 053M STFI Tester SN: 1035

Contact:	Roman Popil	**Next Calibration Due:**	May-12
Company:	IPST	**Date of Visit:**	6/14/2011
Location:	Atlanta, GA	**Purchase Order No.:**	Credit Card
Phone:	(404) 894-9722	**Work Order No.:**	5811044
Fax or E-Mail:	roman.popil@ipst.gatech.edu	**Standard:**	T826
		Customer ID: (If applicable)	#1

General Checks/Maintenance:

		As Found	As Left
Clean and lubricate apparatus			OK
Check incoming air pressure, battery			OK
Function of printer, keyboard, and display			OK
Check clamping distance	Set Value 0.7 +/- 0.05 mm	0.7	0.7
Measured distance at end limit	Set Value 0.2 +/- 0.05 mm	0.2	0.2
Clamp speed	Set Value 3.6 +/- .3 mm	3.05	3.65
Load Cell AD Value	Set Value 40 +/- 10 units	30	41
Moisture Meter AD Value	Set Value 40 +/- 10 units	52	41
Check Moisture Sensor	Set Value 12.2% +/- 0.3%	12.2	12.2

Clamp distance = 0.7 mm

Clamp speed = 3.6 mm/min (adjusted to meet spec)

Calibration of Load Cell: +/- 1% within 10 - 100% of full scale

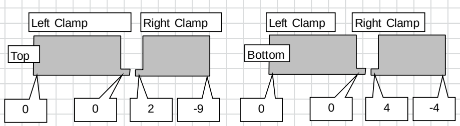
As Found					As Left				
Set (lb)	Set (lb)	Tol.(±)	Read	Dev.	Set (lb)	Set (lb)	Tol.(±)	Read	Dev.
2.20	2.20	0.02	2.00	-0.20	2.20	2.20	0.02	2.20	0.00
4.41	4.41	0.04	4.39	-0.02	4.41	4.41	0.04	4.41	0.00
11.20	11.20	0.11	11.30	0.10	11.20	11.20	0.11	11.30	0.10
22.05	22.05	0.22	22.50	0.45	22.50	22.05	0.22	22.60	0.55

Load cell check using dead weights

Check/Calibration of instrument with Working Standards:

	As Found	As Left
Check Value	20.25	20.35

Clamp Alignment Check: Advanced Calibration



Clamp alignment check

Comments

Please note there is no adjustment for clamp alignment, the clamp will need to be replaced if test results are lower than normal, and the clamp is out of tolerance. Replaced clamp 2094 with new clamp 2167 10/30/2007

All calibration tools are calibrated and traceable to NIST standards:

Grip Weights	OKZN,ZM,ZO	Stop Watch	
Gauge Blocks		Alignment Tool	

Apparatus Approved Yes XXX No

Submitted by: Lee Hornsby (Name) Customer Support Engineer (Title)

Form LWU053 Cal Ver 1 Rev 1 Appr STW Distr Service 6/1/2011

An example of the effect of moisture

Excerpted from Popil and Schaepe, August 2005 Tappi Journal

].[19] Studies at IPST have shown that RC, or similarly the short span compression strength STFI dependence on moisture can be described by the empirical relation:

$$STFI(m), RC(m) = STFI_0, RC_0\, 1.89\ e^{-0.09(M)} \qquad (3)$$

where, M is the percent moisture content by weight of the linerboard and the 0 subscript denotes the values of RC or STFI for samples equilibrated at 50% RH Tappi Standard testing conditions [26][20]. Exposure to high humidity conditions can increase the moisture content of liner to 11% lowering the strength properties according to Equation 3 and, consequently, Equation 1 by 30 percent. Therefore, keeping box components dry as possible is important in maintaining corrugated board strength.

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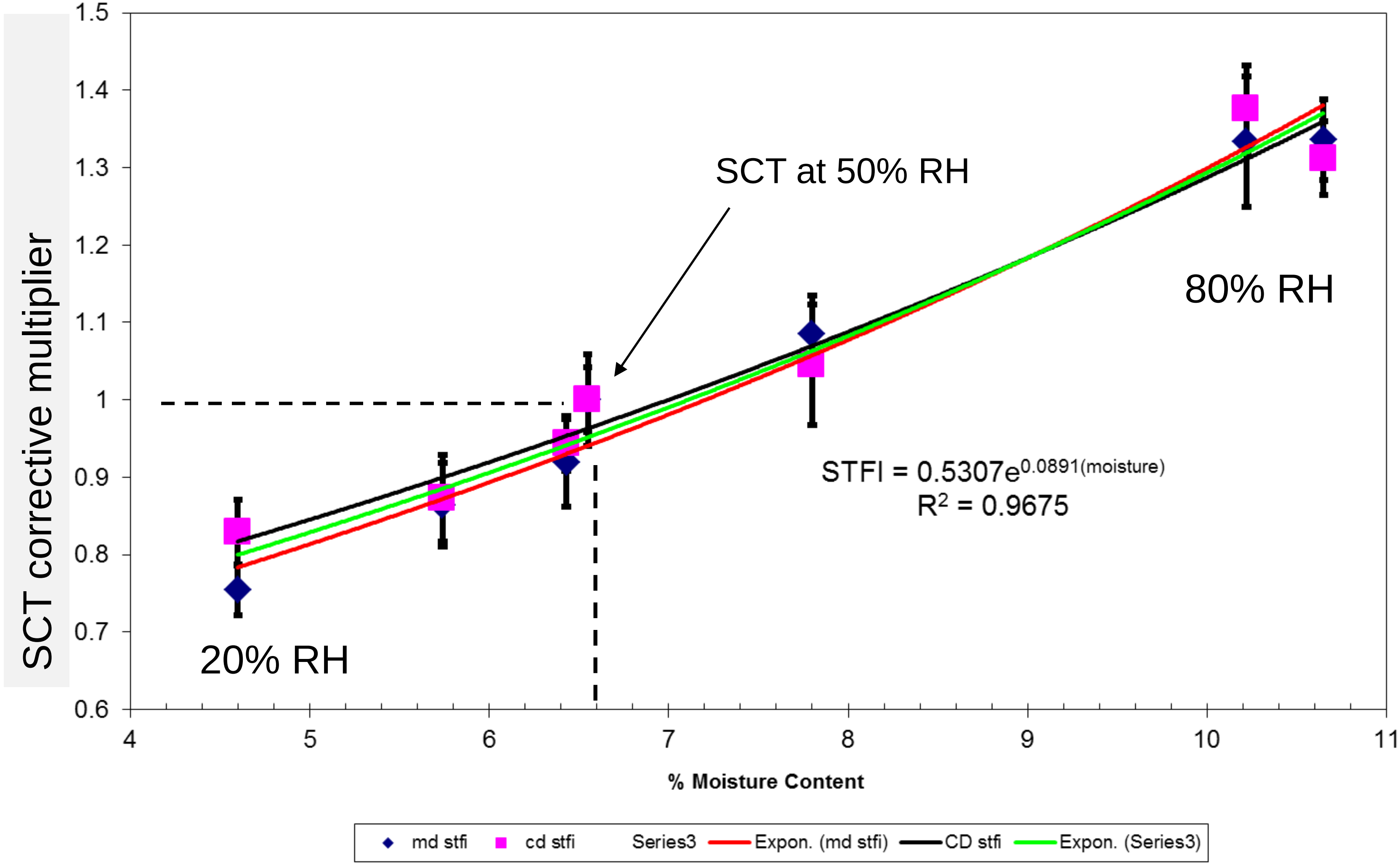
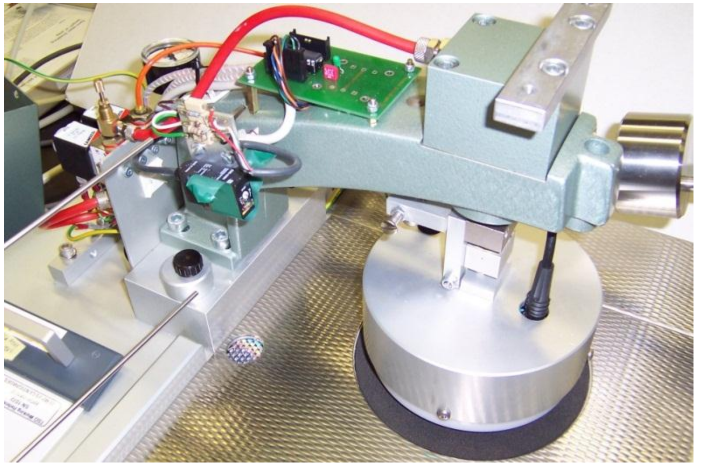
[26] Lehti,S.T., Ketoja, J.A.,Niskanen, K.J., "Measurement of Paper Rheology at Varied Moisture Conditions" 2003 International Paper Physics Conference, September 7-11, 2003, Victoria, British Columbia. 57 – 63,
[27] Tappi test method T402 "Standard conditioning and testing atmospheres for paper, board, pulp handsheets, and related products".

Mill requested study for SCT correction factors for unbleached kraft liner. (SCT built-in moisture correction requires cal for each grade and pulp type – never used at IPST)



To reduce variation to ~3 %

- Measure tensile strength instead, check relationship of tensile with SCT for each grade or major process changes



TSO is quick, low variability, no sample prep required

- Use TSI_CD x basis wt (= tensile stiffness), correlate with SCT, less variation

How this works: tensile stiffness = modulus x thickness, so

$$\boxed{E_{CD}t = \rho V^2 t = \frac{BW}{t}V^2 t = BW \times TSI\_CD}$$

Why this works

Mechanics theory supports the relationship between fiber modulus and SCT

A MODEL FOR SHORT-SPAN COMPRESSIVE STRENGTH OF PAPERBOARD

Paul Shallhorn, Shuohui Ju, and Norayr Gurnagul

Pulp and Paper Research Institute of Canada,
Pointe-Claire, QC, Canada

Can affect this by low consistency refining

$$\frac{1}{\sigma_c} = \frac{1}{\sigma_0} + \left[\frac{Cw}{(2\alpha E_f t^3)}\right]\left(\frac{\rho_f}{\rho} - 1\right)^2$$

Note the dependence on fiber modulus (fibril angle,species)

and sheet density (wet pressing)

where σ_c is the sheet compressive strength, i.e. short-span compressive strength, σ_0 is the sheet compressive strength at limiting high density (the mean fibre compressive strength), C is fibre coarseness, w is the fibre width, α is an efficiency factor, E_f is the average fibre modulus, t is the collapsed fibre thickness, ρ_f and ρ are the fibre (cellulose) and apparent sheet density respectively.

Relationships between mechanical and sonic (TSO) modulus is known.

Higher wet pressing density leads to higher modulus.

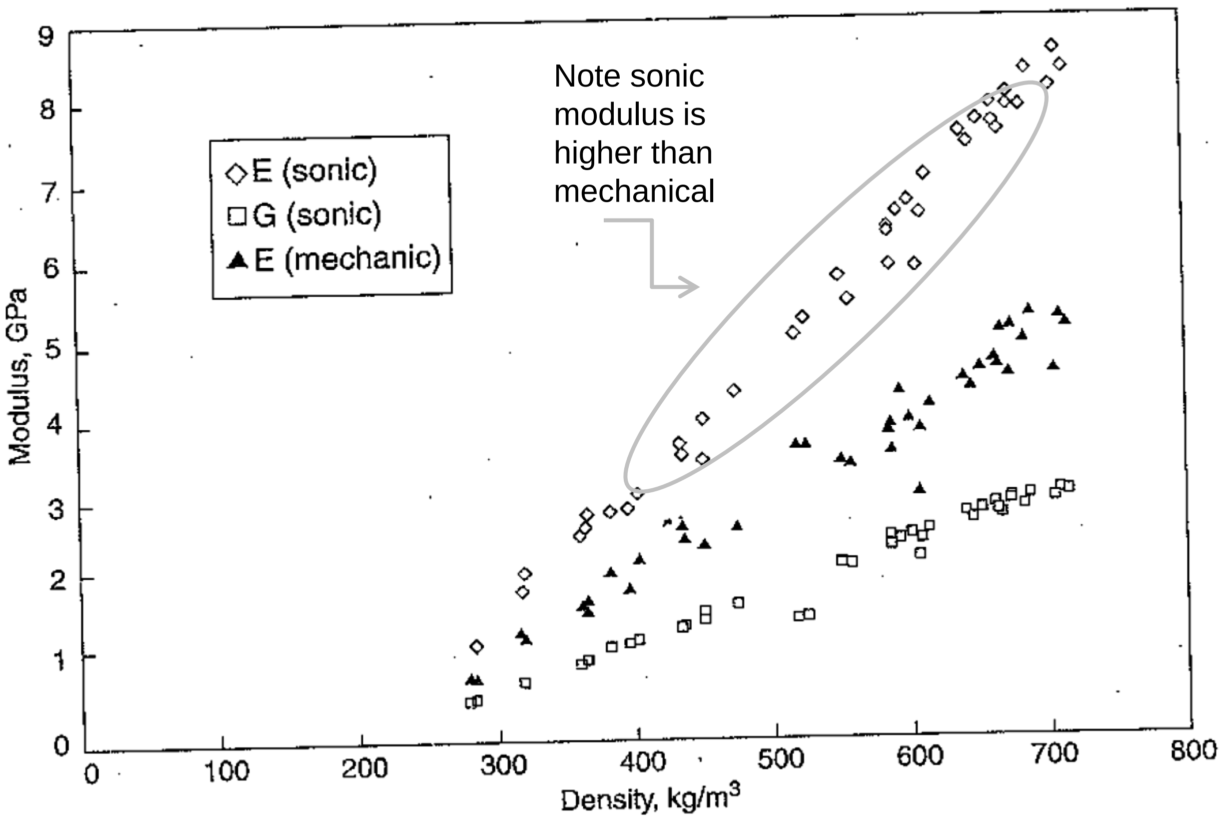


Figure 3. Elastic modulus, E, of bleached kraft pulp handsheets of different basis weights measured ultrasonically (diamonds) and mechanically (triangles). Ultrasonic value for G shown by squares.

From Niskanen's Paper Physics, Tappi Press.

Beating (refining) and wet pressing both increase density increase modulus increase strength. Therefore, measure modulus measure strength with less variation to measure changes in SCT.

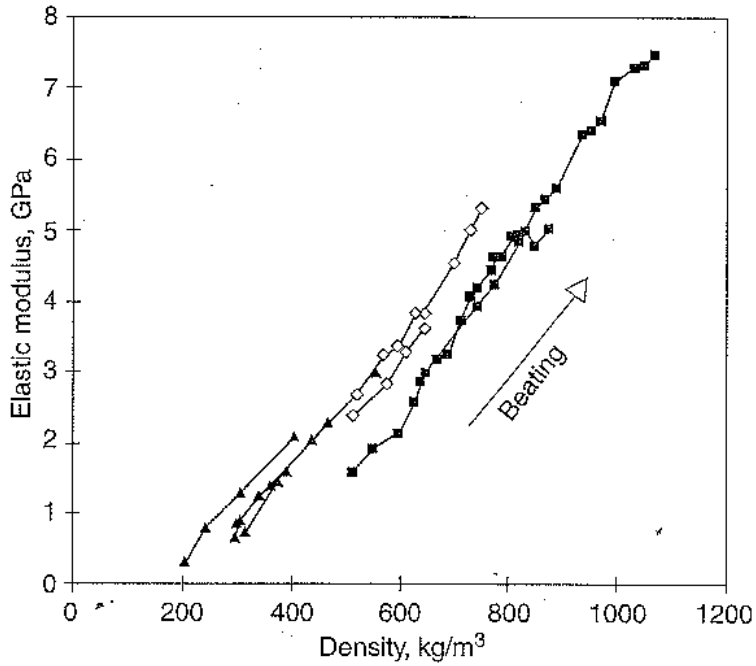


Figure 5. Elastic modulus vs. density when beating varies. Each line connects the data for one wood species, pulp type, and fixed wet pressing level[20,21].

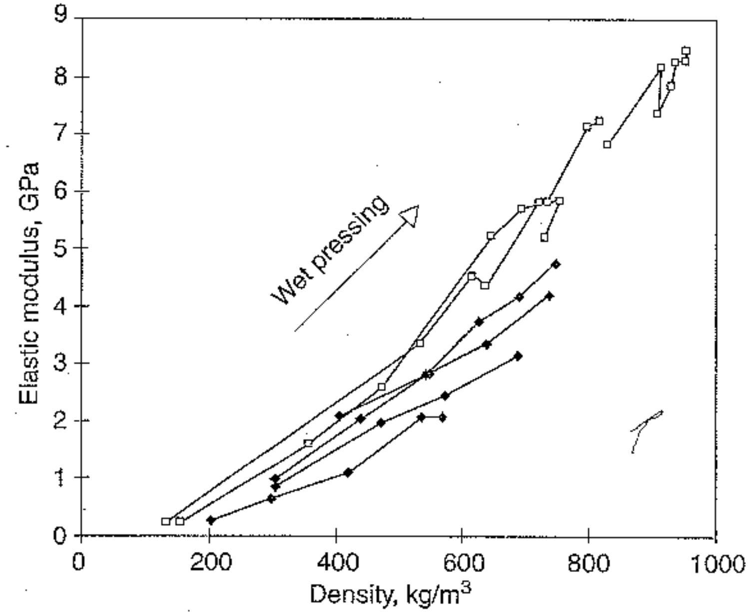


Figure 6. Elastic modulus vs. density when wet pressing varies. Each line connects the data for one wood species, pulp type, and fixed beating level[21].

Example of correlation compression strength and modulus from literature

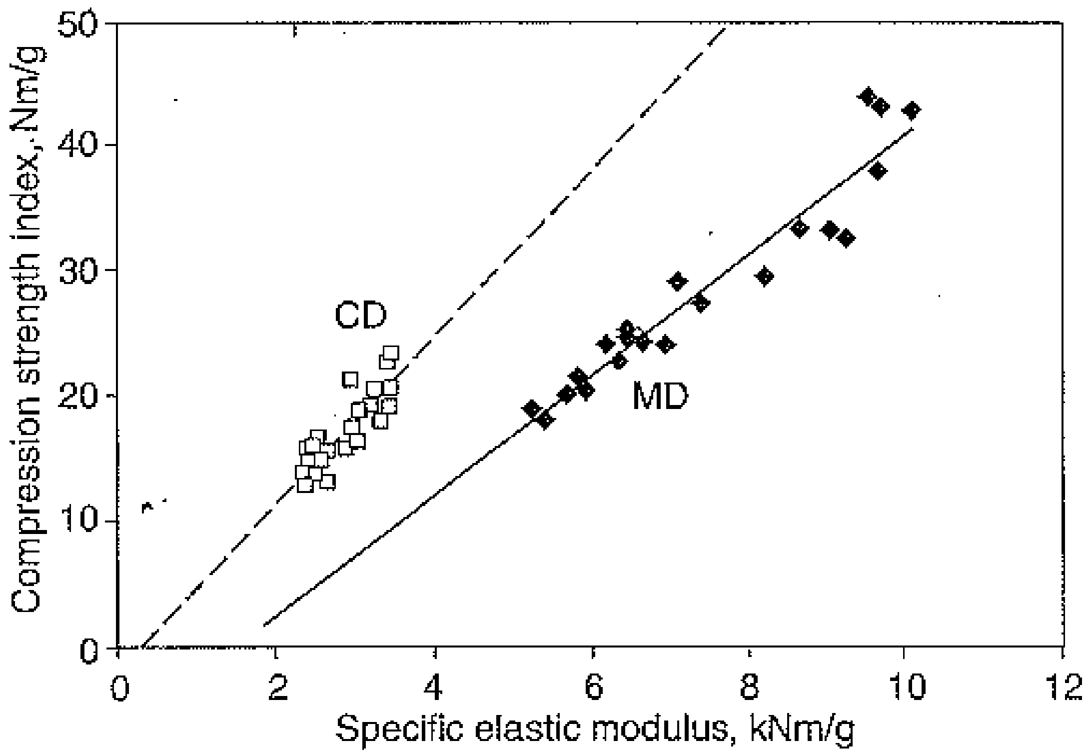
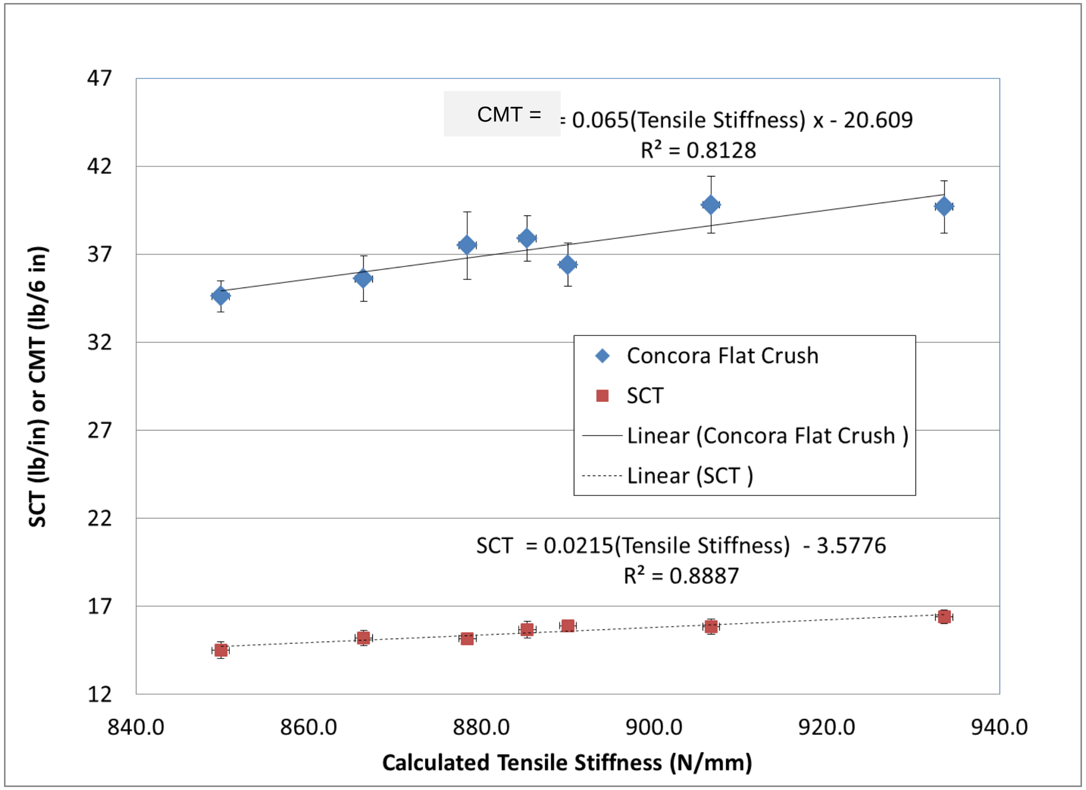


Figure 6. Compression index vs. specific elastic modulus in MD and CD (diamonds and squares, respectively) of machine-made liquid packaging board, liner, fluting, and folding boxboard (with one-sided and two-sided coating).

Recent IPST client Handsheet study, shows correlation of TSO with SCT, CMT

Sample ID	Weight	Basis wt	TSO V2		Tensile st		CMT		SCT	
	g	g/m^2		c.i	N/m	c.i	lb/6 in	c.i	lb/in	c.i
Control	2.24	115.5	7.36	0.07	849.8	8.1	34.6	0.9	14.49	0.48
A	2.29	118.0	7.5	0.04	885.3	5.2	37.9	1.3	15.68	0.48
B	2.26	116.5	7.54	0.04	878.4	4.1	37.5	1.9	15.17	0.26
C	2.38	122.7	7.61	0.05	933.6	6.5	39.7	1.5	16.39	0.40
D	2.38	122.7	7.39	0.12	906.6	15.1	39.8	1.6	15.84	0.43
E	2.25	116.0	7.47	0.09	866.4	10.2	35.6	1.3	15.19	0.44
F	2.29	118.0	7.54	0.06	890.0	7.2	36.4	1.2	15.9	0.32

L&W TSO V^2 (aka *specific stiffness*) x Basis wt = Tensile stiffness, this correlates with SCT and CMT :



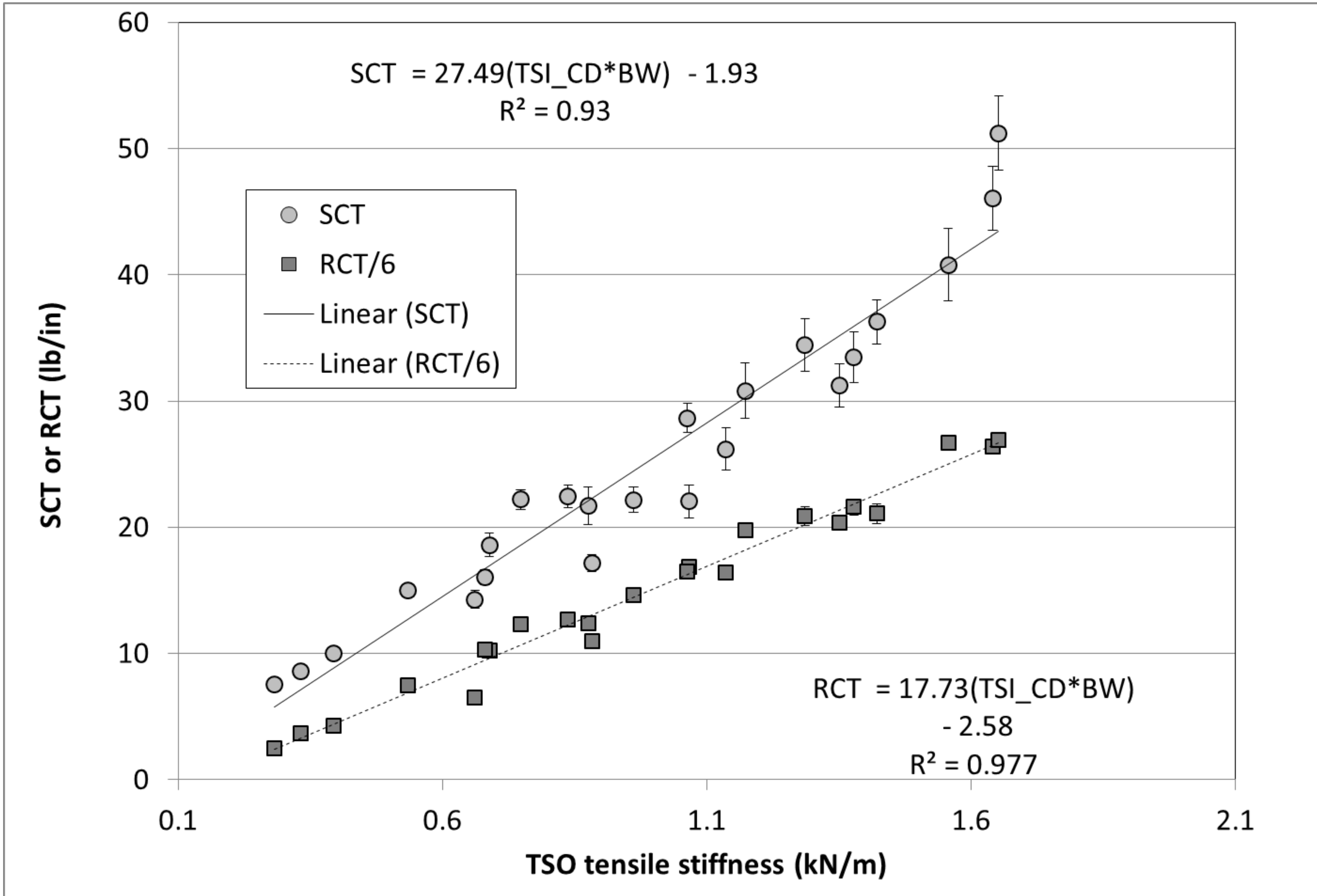
Collection of commercial linerboards and medium from US southeast mills data collected for Tappi PaperCon 2010 conference paper

Sample	Caliper	Basis Weight	TSI-CD	CD SCT	Ring Crush
	(mm)	(g/m^2)	($(km/s)^2$)	(lb/in)	(lb)
Liner A1	0.232	150.1	4.59	18.6	61.5
Liner A2	0.268	171.7	4.88	22.4	76.1
Liner A3	0.305	195.3	5.46	22.1	101.2
Liner A4	0.392	249.5	4.7	30.8	118.4
Liner A5	0.420	275.7	4.9	31.2	122.4
Liner A6	0.476	293.9	4.69	33.5	129.6
Liner B1	0.600	370.4	4.43	46.1	158.4
Liner B2	0.427	277.1	5.13	36.3	126.5
Liner B3	0.725	437.1	3.78	51.2	161.5
Liner B4	0.327	206.3	5.51	26.2	98.5
Liner B5	0.663	393.1	3.96	40.8	160.2
Liner B6	0.260	167.0	5.24	21.7	74.3
Liner B7	0.524	323.8	3.97	34.4	125.4
Liner B8	0.229	149.6	4.55	16.1	62.0
Liner B9	0.322	195.8	5.43	28.6	98.8
Liner B10	0.319	205.4	4.68	22.2	87.8
Liner B11	0.203	128.9	5.13	14.3	39.0
Liner B12	0.259	177.6	4.97	17.2	65.7
medium 1	0.146	78.5	3.58	7.5	15.2
medium 2	0.192	88.3	3.76	8.6	21.9
medium 3	0.197	95.7	4.12	10.0	25.5
medium 4	0.208	126.9	4.21	15.0	45.0
medium 5	0.251	163.7	4.57	22.2	74.1

SCT and RCT correlate with L&W (TSI_CD x Basis wt.)

TSI_CD x Basis wt = elastic modulus x caliper = tensile stiffness

TSI_CD x Basis wt. is a good predictor of SCT and RCT



Modulus and strength connection in a sheet forming study - example

M. Östlund, BiMaC Innovation, Department of Solid Mechanics, KTH (Royal
Institute of
Technology), Stockholm, Sweden.

PACKAGING TECHNOLOGY AND SCIENCE
Packag. Technol. Sci. 2011; 24: 331–341

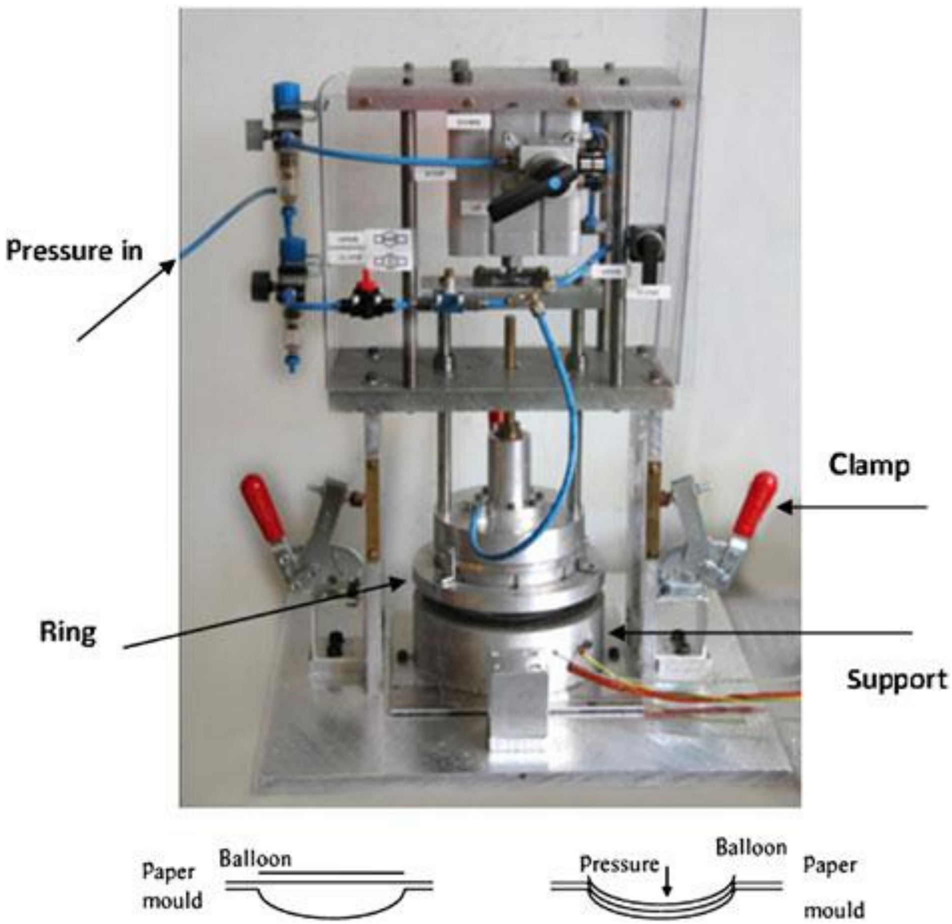
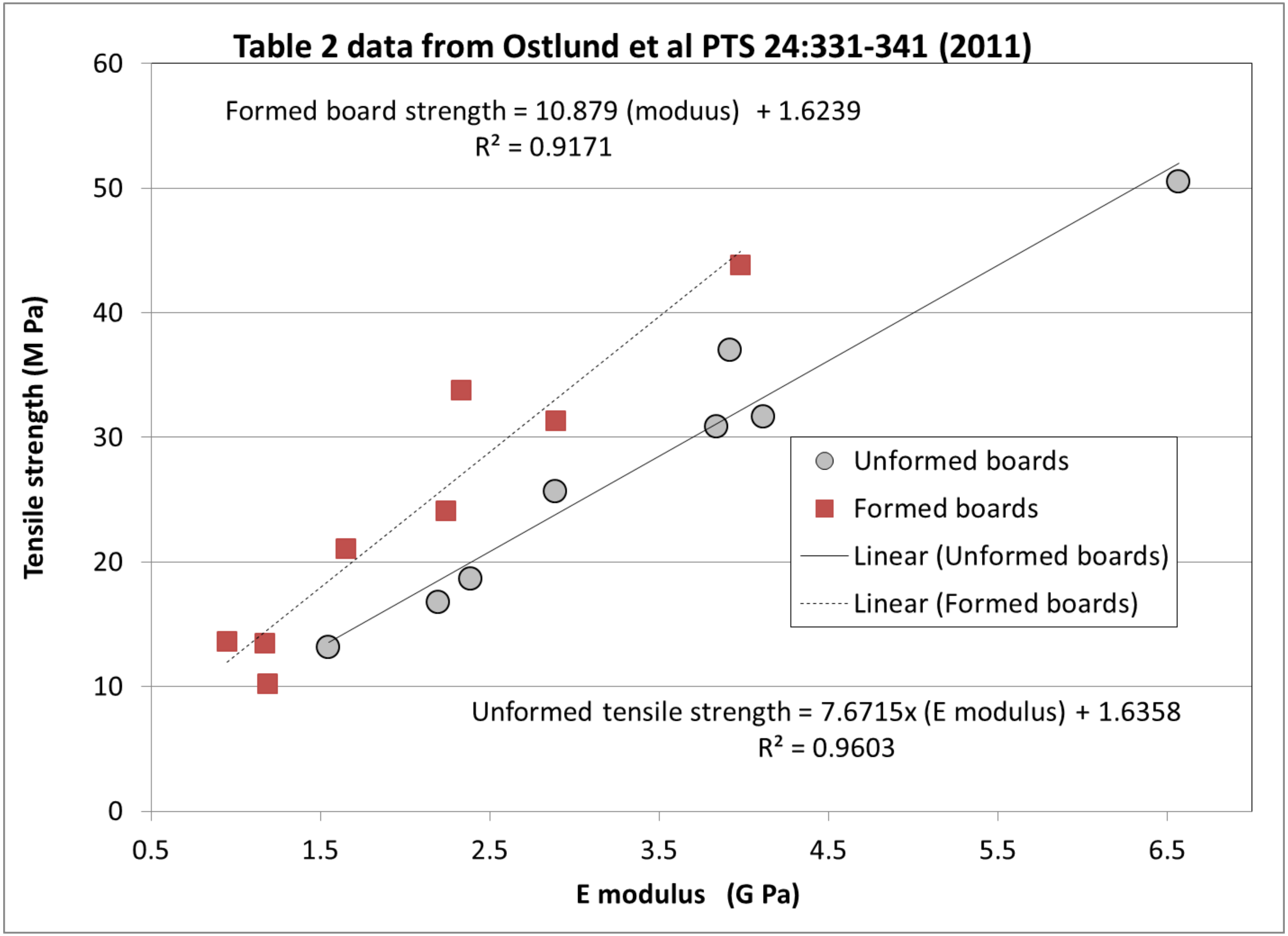


Table 1. Pulp types and average thickness of the 300 g/m2 boards.

Type	Average thickness, μm
PL (unbeaten hardwood)	451.4
PB (unbeaten softwood)	582.0
LEM (commercially beaten hardwood)	324.7
BEM (commercially beaten softwood)	443.0
BS (bleached chemical pulp)	474.6
OS (unbleached chemical pulp)	475.6
CTMP (chemo-thermo-mechanical pulp)	736.4
3S (three-ply board made of OS, CTMP, BS)	

Tensile strength correlates with modulus before and after forming



Effect of CD Position on Strength: Fiber orientation and Shrinkage.

MD/CD strength ratio follows hygroexpansivity profile

From Niskanen, Paper Physics

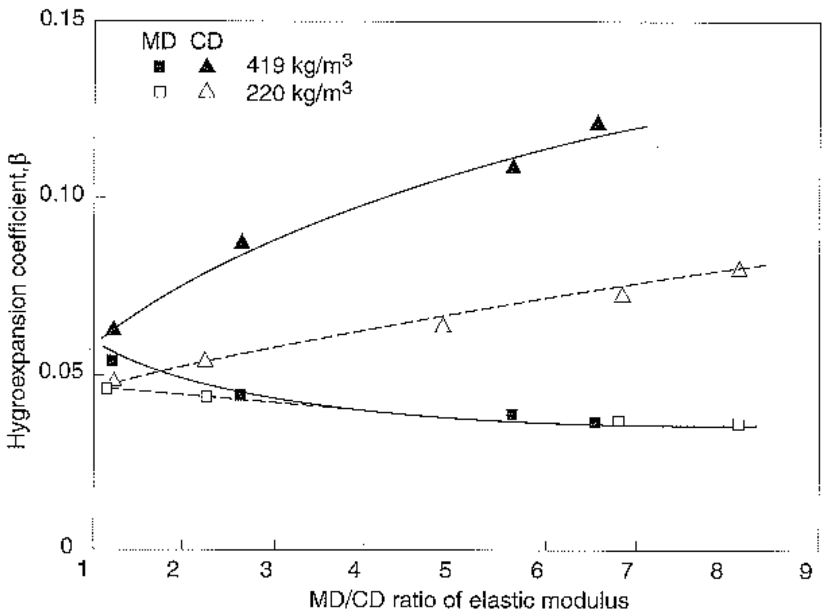


Figure 11. Effect of fiber orientation on the hygroexpansion coefficient, b, in MD (squares) and CD (triangles) vs. the MD/CD ratio of elastic modulus for freely-dried handsheets with anisotropic fiber orientation for unbleached softwood kraft pulp with two density levels of 419 and 220 kg/m^3 (solid and dashed lines, respectively) changed by wet pressing[28].

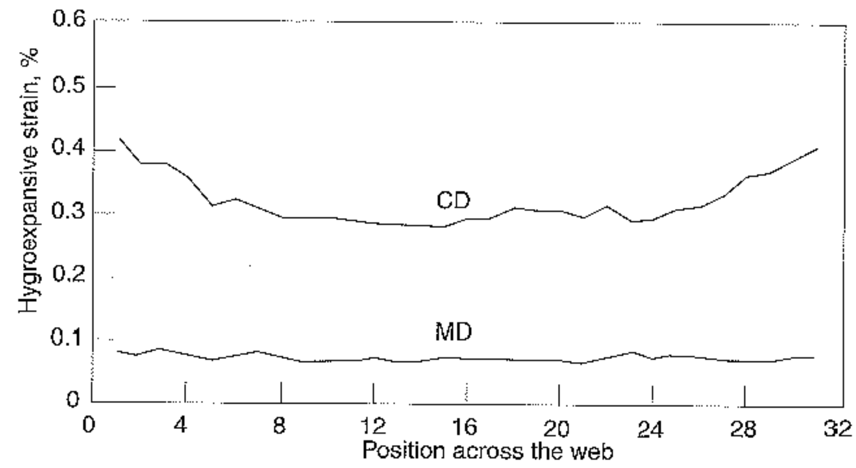
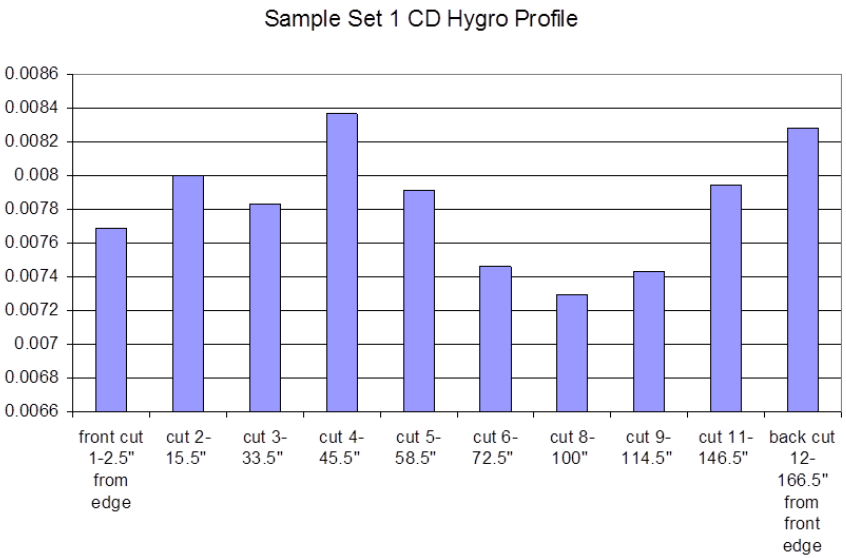
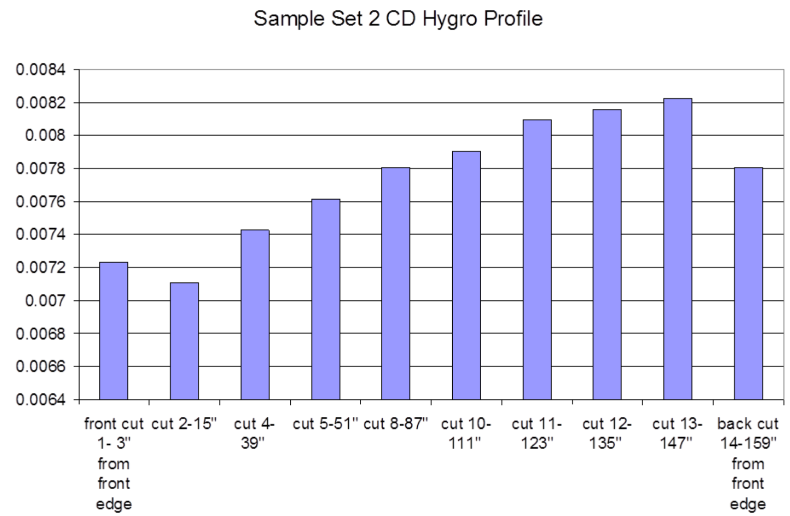


Figure 13. Variation in MD and CD hygroexpansive strain, ε_h, across the width of a full-size paper web for a change in RH from 33%–66% at $T = 23°C$[22].

IPST data: CD hygroexpansivity, Southeast GA mill unbleached softwood kraft linerboard, front to back





A 10% variation in CD hygroexpansivity from front to back is typical, the same profile variation can be expected for CD SCT

New Proposals for Funding at IPST

Title: Reduced Variability in the Quality Control of PaperBoard

Personnel: Roman Popil, Rallming Yang

Typical variation in strength values for paper and paperboard are of the order of 5 to 8% which requires average values of produced materials to be higher than product spec values to avoid field failures. Meeting products specs with the incipient high variability in testing results comes often at the cost of higher basis weight, chemical additives, etc. Measurement of sound transmission through and along paper samples have been shown to correlate with elastic stiffness and strength values since 1965 and extensively at IPST. Moreover, these measurements have a) a higher sensitivity to process changes than equivalent mechanical tests, b) smaller variability, typically around 3%, c) do not require mounting, cutting, handling or sample preparation for testing d) are now widely commonly available in commercial on-line testing systems. The opportunity abounds to improve quality control in production facilities by replacing traditional mechanical methods with more sensitive, precise, faster ultrasonic measuring techniques. The proposal aims to assert and quantify mechanical quality to ultrasonic measurements e.g., RCT or SCT to measured sonic velocities, firstly through a systematic study using laboratory prepared samples of varying density, refining, bonding etc., and secondly substantiated with a commercial range of fiber-based products. The result will be a series of mechanistic mathematical relationships with specified accuracy to allow faster sonic measurements to replace traditional mechanical testing.

New Proposal for Funding at IPST

Title: Development of calibration method for short span compression

Short span compression (SCT) is used extensively for the quality characterization and marketing of linerboard for use in corrugated containers. Repeatability and reproducibility for this measurement is a frequent concern for using the values to meet product marketing specifications. Comparison between instruments is obfuscated by the inherent variability in paper samples. This project proposes to develop artificial calibration strips which will have a high uniformity allowing accurate assessment of instrument R&R. The material must have an approximate comparable elastic modulus and strain- to-failure emulating typical paper behavior. Experience with composite pigment/polymer films have shown that a suitable combination of binder and pigment can be selected to approximate the compression stress-strain behavior of paperboard. Such materials can be prepared in thin film strip form and be tested in conventional SCT instruments

New proposal for funding at IPST

Title: Optimizing the tensile test for reduced variability

Tensile strength and stiffness are routinely used to qualify paper products for the marketplace. These properties are required for paper to endure conversion and printing processes. Parameters for the test have long been established by committee yet there is an ever present requirement for reduced basis weight which can only be met with testing that has reduced variation. Previous research work using laser speckle photography has revealed stress concentration occurring in the scale of the average floc size. Therefore, it may be expected that reduced variability in the tensile test may be attained with the use of wider samples than the accepted standard. This project aims to investigate the nature of the variability of the tensile test to establish optimal test sample dimensions such that the variability in the test is appreciably reduced. The result would be new test specimen parameters that will provide lower variation in the test averages than current practice.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