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

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

Error bars in c.i. decrease as $1/\sqrt{n}$, Tappi standard is $n = 10$

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

$n = 150!!$

18.42 ± 0.93 (5%) @IPST
19.41 ± 1.25 (6.4%) at mill
R&R data: 2 instruments, same MD position, 3 operators

<table>
<thead>
<tr>
<th>Variable</th>
<th>Sample</th>
<th>Count</th>
<th>Total Mean</th>
<th>StDev</th>
<th>CoefVar</th>
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<td>1.009</td>
<td>4.72</td>
<td>3.400</td>
</tr>
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</table>
Comparison of SCT of 2 Instruments

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

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

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

mean reproducibility 4.101

gauge r&r % 5.499

4 confidence interval/mean value

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

% delta

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

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)
Sources of variation - formation

160 mm

15 mm

Strip width is about 2 flocs wide

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!!
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.

Sample cut along the MD
Cutting strips with a punch cutter at the same MD position contiguously should reduce sample variability.
Other effects - speed

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

- Clamp distance = 0.7 mm
- Clamp speed = 3.6 mm/min (adjusted to meet spec)
- Load cell check using dead weights
- Clamp alignment check

**General Checks/Maintenance:**

- Clean and lubricate apparatus
- Check incoming air pressure, battery
- Function of printer, keyboard, and display
- Check clamping distance
  - Set Value 0.7 ± 0.05 mm
  - As Found: 0.7
  - As Left: 0.7
- Measured distance at end limit
  - Set Value 0.2 ± 0.05 mm
  - As Found: 0.2
  - As Left: 0.2
- Clamp speed
  - Set Value 3.6 ± 0.3 mm
  - As Found: 3.05
  - As Left: 3.65
- Load Cell AD Value
  - Set Value 40 ± 10 units
  - As Found: 30
  - As Left: 41
- Moisture Meter AD Value
  - Set Value 40 ± 10 units
  - As Found: 50
  - As Left: 41
- Check Moisture Sensor
  - Set Value 12.2% ± 0.3%
  - As Found: 12.2%
  - As Left: 12.2%

**Calibration of Load Cell:**

<table>
<thead>
<tr>
<th>As Found</th>
<th>As Left</th>
<th>Set (lb)</th>
<th>Tol.(±)</th>
<th>Dev.</th>
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<td>2.20</td>
<td>0.00</td>
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<tr>
<td>4.41</td>
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<td>0.04</td>
<td>4.41</td>
<td>0.00</td>
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<td>11.20</td>
<td>11.30</td>
<td>0.11</td>
<td>11.20</td>
<td>0.10</td>
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<tr>
<td>22.05</td>
<td>22.05</td>
<td>0.22</td>
<td>22.05</td>
<td>0.22</td>
</tr>
</tbody>
</table>

**Check/Calibration of instrument with Working Standards:**

- Check Value: 20.25, 20.35

**Clamp Alignment Check:**

- No adjustment needed; the clamp alignment was within tolerance.
- Replaced clamp 2094 with new clamp 2167 on 10/30/2007

**Comments:**

- All calibration tools are calibrated and traceable to NIST standards:
  - Grip Weights
  - Gauge Blocks

- Apparatus: Approved Yes, Not Approved No

- Submitted by: Lee Hornsby, Customer Support Engineer

Form LWU053 Cal Ver 1 Rev 1 Appar US SW Dist Service 6/14/2011
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:

\[ STFI(m), RC(m) = STFI_0, RC_0 1.89 e^{-0.09(M)} \]  \hspace{1cm} (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]. 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.

[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)

\[
\text{STFI} = 0.5307e^{0.0891(\text{moisture})} \\
R^2 = 0.9675
\]
To reduce variation to \( \sim 3\% \)

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

- Use TSI\textsubscript{CD} x basis wt ( = tensile stiffness), correlate with SCT, less variation

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

\[
E_{CD}t = \rho V^2 t = \frac{BW}{t} V^2 t = BW \times TSI\textsubscript{CD}
\]

TSO is quick, low variability, no sample prep required
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

Note the dependence on fiber modulus (fibril angle, species) and sheet density (wet pressing)

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

where $\sigma_c$ is the sheet compressive strength, i.e. short-span compressive strength, $\sigma_0$ is the sheet compressive strength at limiting high density (the mean fibre compressive strength), $C$ is fibre coarseness, $w$ is the fibre width, $\alpha$ is an efficiency factor, $E_f$ is the average fibre modulus, $t$ is the collapsed fibre thickness, $\rho_f$ and $\rho$ 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\textsuperscript{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\textsuperscript{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.

<table>
<thead>
<tr>
<th>Sample ID</th>
<th>Weight</th>
<th>Basis wt</th>
<th>TSO V2</th>
<th>Tensile st</th>
<th>CMT</th>
<th>SCT</th>
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<td>0.07</td>
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<td>7.5</td>
<td>0.04</td>
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<td>7.54</td>
<td>0.06</td>
<td>890.0</td>
<td>36.4</td>
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</table>

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

\[
CMT = 0.065(\text{Tensile Stiffness}) \times 20.609 \\
R^2 = 0.8128
\]

\[
SCT = 0.0215(\text{Tensile Stiffness}) \times 3.5776 \\
R^2 = 0.8887
\]
Collection of commercial linerboards and medium from US southeast mills data collected for Tappi PaperCon 2010 conference paper

<table>
<thead>
<tr>
<th>Sample</th>
<th>Caliper (mm)</th>
<th>Basis Weight (g/m²)</th>
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<th>CD SCT (lb/in)</th>
<th>Ring Crush (lb)</th>
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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

\[
\text{SCT} = 27.49(\text{TSI_CD} \times \text{BW}) - 1.93 \\
R^2 = 0.93
\]

\[
\text{RCT} = 17.73(\text{TSI_CD} \times \text{BW}) - 2.58 \\
R^2 = 0.977
\]
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

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

Table 2 data from Ostlund et al PTS 24:331-341 (2011)

Formed board strength = 10.879 (modulus) + 1.6239
R² = 0.9171

Unformed tensile strength = 7.6715x (E modulus) + 1.6358
R² = 0.9603
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 $\beta$, 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.

**Figure 13.** Variation in MD and CD hygroexpansive strain $\varepsilon_h$ across the width of a full-size paper web for a change in RH from 33%-66% at $T = 23^\circ C$.22
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.
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.
When you need testing or research on a problem

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