Newsletter Update: Progress in Packaging and Paper Physics at IPST/GT

January 2009

Figure 1. Hard at work as always, from left to right, the talented Shirley Whitfield, "Mystery Guest" Physics Professor Emeritus Gary Baum and the equally enigmatic Roman Popil, butchering a version of Elvis's "Blue Christmas", Member's Lounge, Dec 2008.

In this issue:

- **Score cracking – how to predict it without cracking up**
- **Simple form of the McKee equation - now corrected for board crush**
- **A better way to measure pin adhesion – higher sensitivity , better for trouble-shooting**
- **Corrugating lab move to 10th St PTB – hey, we *still* got the best stuff here!**
- **Box lifetime…the right coating can increase it significantly, why not?**
- **Can we finally get rid of Ring Crush testing?**
- **Latest on thin film metering, big plans for FY 10 and beyond…**

The *Move* from 14th St IEC

Figure 2. Mike Schaepe with Robert Hall (far left in picture) tending the 1956 Langston pilot single facer the last time at the IEC, IPST July 25th 2007.

It has been 2 years now since Mike Schaepe has left IPST and in December 2008 the Langston Corrugator has finally been dismantled and relocated to Kohler Coatings in Ohio with the agreed understanding that once up and running, it will be available for trial work for IPST. The absence of the single facer along with its accompanying starch cooker, Langston scorer-slitter makes the option of making unique corrugated board structures at IPST unavailable. Previously we made all kinds of unusual board structures to prove a point such as A flute made with super lightweight medium or C-E double wall boxes. However, the research in corrugated board can be continued by having boards supplied by box-plants. Indeed, the effort on the effect of crush on the McKee equation was recently done using a series of box blanks previously prepared.

Although the larger machines in the pilot plant could not be moved over to the 10th St PTB, a great many of the items have been relocated from IEC at research budget expense. From the Corrugating Lab we have moved the Emerson 7200 box 20,000 lb compression tester, the Double-Blacker Simulator, Honshu AF&PA score crack tester, pneumatic slotter, glue nip applicator, puncture tester, Frazier porosimeter, large board cutter. A Valley beater, Formette Dynamique sheet former, sheet press and drier have also been moved from the IEC through Tim Patterson's efforts. The glue nip applicator is useful as variable gap nip which has been used for the crushing of boards. It was previously extensively used for manual double-backing of samples from the single-facer. With the equipment moved over and now in good running order, the research work can continue on at the PTB on 10th St.

Double-backer Simulator retrofit

This piece of equipment has been around IPST since 1989 and has been made famous by fundamental green bonding studies by Hiroki Nanko (now at Meadwestvaco) and Mike Schaepe (now at Cargill) and later as a test bed for the nanostarch based coatings now marketed by Ecosynthetix. Single face strips 12 x 2” are affixed underneath a travelling carriage. Once started, the carriage traverses the single facing over an IR lamp to preheat it prior to carrying the single facing over a heated and rotating glue applicator after which a trip of medium is adhered and pressed at 250 deg F for a prescribed number of seconds. A load cell immediately after the press section measures the strength of the green bond after pressing but lately, the process is stopped at this point and the double backed samples are retrieved for physical testing such as pin adhesion, bending stiffness, ECT.

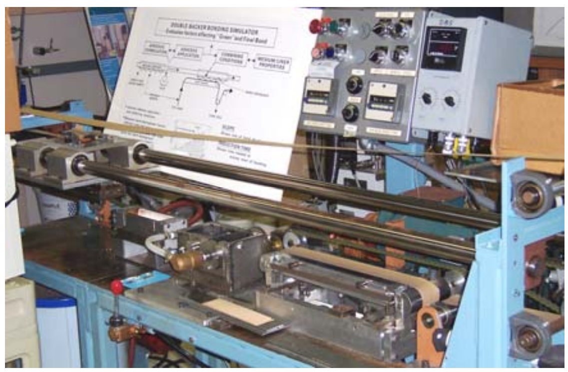


Figure 3. Double backer simulator now running and installed at PTB 10t St. The glue machine is now a wire-rod metered soft-rubber roll for thin film metering experiments.

Kohler Coatings have advocated thin film metered adhesive application and have successfully made several installations of their glue applicators. The reduced adhesive application saves about 60% in energy and materials. Additionally, the lowered board wetting and heating associated with smaller application of adhesive is said to increase performance properties of the board such as ECT and pin adhesion. Accordingly the DBS gravure roll glue applicator has been replaced with a refurbished glue machine which has a machine soft rubber covered roll with a spring-tensioned wire rod for doctoring the adhesive on the roll. Getting the glue machine made was an extensive undertaking requiring finding a machine shop willing to undertake machining a small soft rubber roll for this application. As before, the glue machine jacket and applicator roll are both maintained at 140 deg F by a circulating fluid heater.

Several different wire rods have been specially ordered and obtained. Initial trials will involve characterizing the adhesive application using PVA diluted to 34% solids for convenience. The intention is to start with approximate standard levels of adhesive application then progress geometrically to lower levels and test the properties of the resulting boards. Maybe we will finally be able to bring a nice wide big smile to Herb Kohler’s face!!

McKee equation for BCT – corrected for board crush

The McKee equation for BCT has been around since 1963 and has received widespread use for predicting the stacking strength of a corrugated box. The original derivation of the equation involved several approximations largely motivated by the unavailability of measurements. The most widely used form of the McKee equation says that box compression strength *BCT* is just proportional to the product of *ECT* and the square root of the board caliper *t* :

$$BCT = C \times ECT \times \sqrt{t}$$

This equation assumes the tensile stiffness of the linerboard facings are proportional to ECT and that bending stiffness is approximated by the linerboard tensile stiffness as well. The properties of the medium are all neglected in t his equation except as a contributor to ECT. However, when the corrugated board becomes squeezed in converting operations such as the press transfer roll or dull die cutters for hand holds, what happens is that the fluted medium acquires irreversible kinks in the shanks of the flutes leading to loss of shear stiffness. This means that the box under load made with such damaged board will have larger out of plane bending strain than a box made with undamaged board. I have crushed off-the-corrugator made boards in varying degrees up to 50% or their original caliper, measured up various properties including transverse shear and found that BCT prediction improves by 27% if the more correct form is used:

$$BCT = C' \times ECT \times \sqrt{t} \times \sqrt[4]{K}$$

The "*K*" in the corrected form of the simple McKee formula is the calculated ratio of bending stiffness with shear to that without shear and is always less than 1. Compared to the uncrushed board, the crushed board samples had caliper up to 23% lower, ECT was up to 27% lower, BCT was 40% lower, transverse shear was 83% lower. So, should a better predictive model for BCT be desired (heck, some people will always want to improve something…), the shear stiffness of the board also has to be measured. but nowadays that is easy !

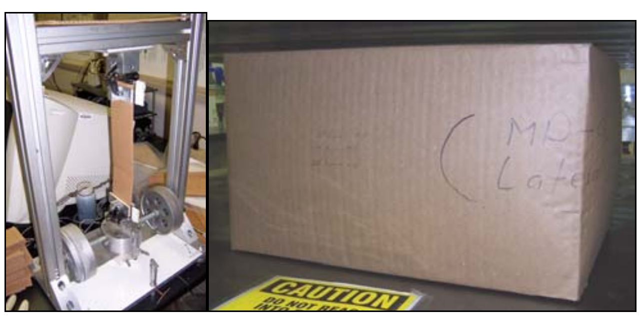


Figure 4. The IPST torsion pendulum on the left, this was written up in Appita Journal in 2008 and validates the BQM hand-held measurement of transverse shear. On the right is a BCT crushed lateral corrugated box. The lifetime of corrugated containers increases when their components are rotated 90 degrees because hygroexpansive strain is less in the MD. This data has been presented at the 2008 Progress in paper Physics Seminar in Finland.

Scoring – it's not what it's "cracked" up to be.

Increased recycle content, starch surface coatings, dry winter conditions singly and in combination can cause the cracking of linerboard when folded into a flap or a corner of a box. For coated magazine papers, cracking at folds causes stapled pages to fall out. In any cases cracking causes failure of the end product whether it be a box filled with contents and stacked in a warehouse or a stapled pamphlet or journal.

Literature on cracking all points to fibers on the convex surface being stressed in curvature beyond their elastic limit. Once these outer surface fibers tear from the stress, the failure propagates through the thickness of the sheet.

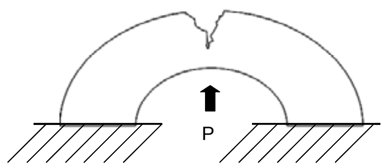


Figure 5. Schematic of the fold crack mechanism: fiber on the outer surface in curved geometry suffer the greatest strain and hence break, causing the crack to propagate through the thickness of the sheet.

A series of test were devised where the strain to failure in curved geometry was measured and the results correlated with score cracking propensity measured through either the MIT fold test or the IPST crack angle measurement. The intention is that the through a combination of Mullen testing and in-plane tensile tests the strain to failure can be calculated and correlated with score crack propensity. The advantage here is that this combination of tests is available in automated in-line systems so that score crack propensity can be essentially predicted continuously for production data.

A sample set of coated linerboards were obtained from a mill and a variety of physical tests were made. Strain to failure in curved geometry was measured directly using a sample formed into a loop around a suspended yoke in a tensile tester machine. In-plane tensile stiffness was calculated using the L&W TSI values multiplied by the basis weight. We find that the MIT MD fold correlates nicely with the caliper normalized crack angle. The calculated strain to failure using a combination of Mullen and in-plane tensile data correlated well with directly measured strain to failure for the loops in tension. The curved sample strains-to-failure whether calculated or measured directly, had about a 63% r squared correlation with the crack angle data for this sample set. So… now we can predict score cracking with automated in-line measurements…beats folding paper all day long and trying to measure those teensy cracks!!

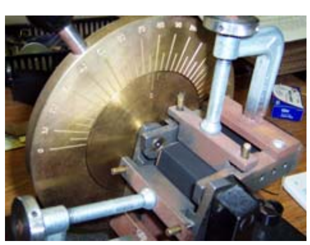


Figure 6. IPST crack angle test, a blackened sample is bent over an anvil and the angle at which cracking starts is noted.

Pin adhesion – a sticky situation can now be measured with greater sensitivity

When pin adhesion values are down what could be wrong? Is it the adhesive level, the adhesive itself, or temperatures too high or too low? An easy but different way of measuring pin adhesion is to place the fixture in an Instron compression tester and collect data on the TEA (tensile energy absorption) during the pin adhesion test. To test this idea, board sample previously demonstrated at a 2003 Tappi Corrugating conference were used, these consisted of:

1 = brittle bond (corrugating temp too high)
2 = white glue lines (corrugating temp too low)
3 = excessive glue application
4 = applicator roll gap excessive should have a random pattern of skips)
5 = clean-out finger too far out (lot of glue streaks)
6 = applicator roll too fast (120%) (get a heavy line on one side of glue line)
7 = applicator roll too slow (67%) - should be ok

The ranking of pin adhesion for this sample set was 2,4,1,5,3,6,7, and the pin adhesions ranged from 10 to 56 lb/ft. Analysis was performed using the load displacement data from the Instron UTM Series IX output which can provide an ASCII file easily analyzed by MS Excel.

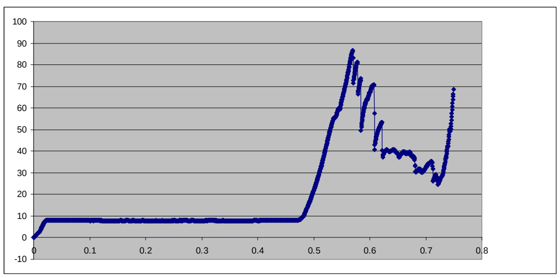


Figure 7. Representative load-displacement (lb vs in) curve for a pin adhesion test. The area under the waveform is analyzed to calculate TEA which is a better measure of board strength than peak load only.

A simple integration by summation in the spreadsheet data produces the TEA which then spans 800 to 19600 lb-in which is 4 times greater the range spanned by peak load. The TEA is more indicatives of the bond having any pliability or plasticity such that it can have more resiliency. For example, a bond using latex rather than starch would be expected to have a much larger TEA for the same peak load since the latex would be much more elastomeric than starch. TEA analysis of pin adhesion is therefore more sensitive to detecting brittleness of starch adhesive bonding. Next time the “pins” are troublesome, you can always amuse yourself and amaze your colleagues by performing the pin adhesion test on an Instron!

A clay coated box not only looks pretty – it will last longer too!

The state of Georgia TIP3 program along with the interests of Imerys have supported corrugated waterproofing projects for several years. One interesting finding is that the WVTR of linerboard can be reduced by the application of a clay coating. Clay coatings can be applied to linerboard using a wire rod coated and this was done 2 years ago at spectra-Kote in Gettysburg.

Figure 8. 42# linerboard being clay coated at Spectra-Kote left, right - a clay coated corrugated box undergoing a BCT retention test after an ice-pack 3 day test.

We showed that clay coated linerboard runs fine on the corrugator although glue lines will show on the single facing side. Kaolin clay can substitute for a base aqueous polymer coating in wax replacement waterproofing operations. Imerys has recently introduced platy clay kaolin coatings which effectively lower WVTR but are not water barrier coatings. These pigmented coatings appear not to have the problems of gluability and printability usually associated with wax replacement polymer coatings. Lowering the WVTR lowers the hygroexpansive strain of a box in a cyclic humidity environment. We have shown that an uncoated box loaded at 22.5% of its failure BCT load placed in a 24 hr period humidity environment sinusoidal variation from 50 to 80% RH limits will last about a week before collapsing. The same clay coated box when under similar circumstances will last about 2 months. The plan is to test the new platy Imerys coatings to quantify and characterize their performance in increasing box lifetime.

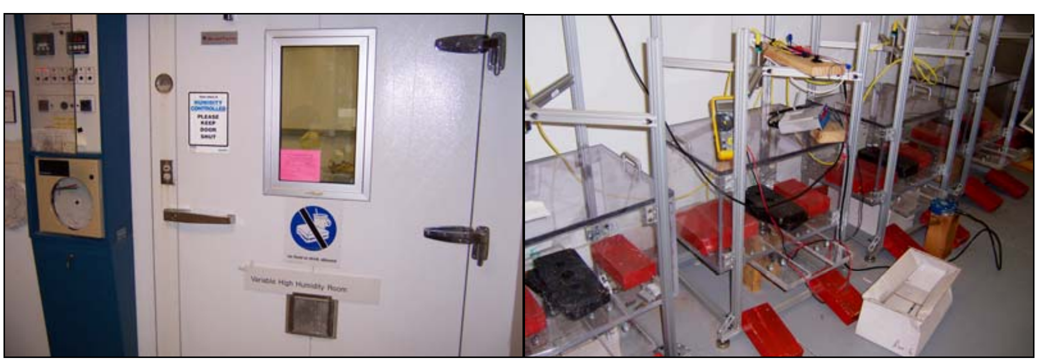
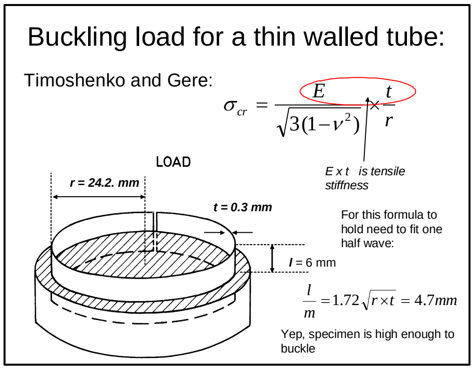


Figure 9. Left - front of the programmable humidity walk-in chamber, right - 3 of the 8 BCT creep stations inside, a post-test crushed clay coated box on floor.

Ring Crush testing – will it ever go away?

Of course, there are some out there that will say Ring Crush is the only way to describe the compression strength of linerboard, but chances are they do not themselves routinely test for ring crush. Historically, RCT has been used to qualify linerboard for box making and is manufactured to an RCT target so RCT values have become familiar to many involved in manufacturing and marketing of paperboard. Unfortunately, the test requires cutting and handling of strips and as it is, the process is not transferrable to automation. I, among others somewhat inclined to erudition, argue that the test is a combination of bending and compression failure and so when optimizing linerboard through refining or densification, RCT can provide misleading information as has been documented repeatedly in the literature. To avoid any uncomfortable Freudian connotation and accompanying smirks, the term *SCT* rather than STFI (pronounced as "stiffy") should be used to describe the short span compression test originally devised in the 1970's by STFI.

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



Studies have been undertaken using a wide range of grammage of linerboards obtained form mills to obtain a relationship between the SCT and SCT compression strengths. To a good approximation, a multiple linear regression with basis weight and SCT can provide a good model for RCT. Using a mechanistic approach, the increased buckling that occurs at lower grammage and caliper can be modeled and measured using a combination of caliper and tensile stiffness measurements. The best predictive model for RCT would have a combination of compression strength and buckling load much in the same way as the McKee formula for box compression strength.

The aim is to provide mills a means of obtaining equivalent RCT values for their products using available automated testing data which excludes RCT. A better picture of what works best will arise once more samples and data is collected from more mills.

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