ECT Literature Review

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An Annotated Bibliography

- Over 250 abstracts were reviewed using Elsevier International PaperChem database, Koning's "Corrugated Crossroads", Maltenfort's "Corrugated Shipping Containers…" going back to 1969
- Over 100 papers were selected for examination
- 50 papers post review are mentioned in the bibliography with a synopsis of their abstracts and/or content

Notes (Background):

IPST has had active research programs in corrugated board for several decades. Many noteworthy contributions have come from this work such as the McKee equation, contributions by Whitsitt, Sprague, Batelka and others, a prediction formula for ECT based on component strengths, ECT measurement methods, and the effects of crushing and boxplant operations on ECT.

Since the merger of IPST with the Georgia Institute of Technology, general research into the nature of ECT continues at IPST through the Elective Research Consortium program sponsored by participating member companies. Objectives of the research delve into the effects of measurement techniques on ECT and the optimization of ECT through either corrugated structure or component property optimization. The bibliography prepared and reviewed here is part of that research program.

The papers can be classified by category

- Effects of paper components on ECT
- Effects of methods, sample prep. on ECT
- Effects of box plant, converting operations on ECT
- Rule 41 and ECT implications

Some interesting issues arise ...

Notes:

The bibliography can be categorized into a few main topics of interest. The effects of the linerboard and medium properties on ECT is an important category since ECT is the main component for most aspects of container performance primarily stacking strength and lifetime. Several studies are reported where the authors have attempted to investigate the effects of component properties on ECT. Some models have materialized which can be utilized in developing a production strategy to optimize ECT on this basis.

Accordingly, ECT is used as a quality control tool in paperboard and corrugated manufacturing operations. Since ECT is generally directly related to basis weight, its accuracy of measurement and minimization or variability can have profound economic consequences. Techniques of measurement have been described in several articles which have attempted to produce a measurement that unambiguously reflects the compressive strength of corrugated board devoid of artifact.

ECT is affected in varying degrees by converting operations as described in the references. Optimization of ECT can only be attained if the effects of transfer nips, printing, die cutting, and scoring are realized.

Optimizing ECT can be advantageous in a program where attempts to reduce basis weight to reduce costs are in effect. Implementation of Rule 41 for shipping containers provides that opportunity.

Investigations into ECT Phenomenon

- Effects of span length, effects of loading rate
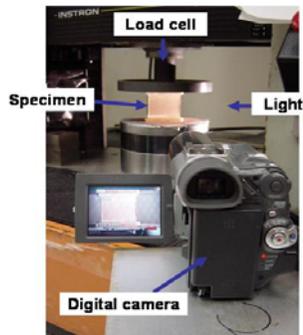
IPST investigations span length, loading rate and of liner inter-flute buckling – sample shot of AC board undergoing ECT

References: Bormett 21, Stockmann 41

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Notes (IPST work):

The IPST investigations of ECT parallel much of what is reported in the literature. For example, a study into the effect of loading rate showed a logarithmic dependence of the ECT value with loading rate. A typical T839 clamp style ECT test occurs in about 6 seconds. Studies were made where the load rate was extended for up to 30 minutes. A longer duration decreases the ECT value as inelastic creep component of the deformation becomes increasingly important. Interesting to note that from the data, the ECT value would be about half its T839 value if the test were to be extended over 2 weeks!

Previous work established the required specimen span lengths for the ECT test. The idea here is to avoid buckling/bending during vertical compression for a given thickness. A series of so-called Euler curves have been developed in the literature and at IPST for the various flute sizes. Turns out that for E flute, which is not usually considered for shipping container construction, can be reliably measured for ECT using the span of 0.4 inches in the T839 method provided good contact is made with the test specimen and clamp.

This slide shows a video set-up of some of the ECT IPST investigations, we attempted to examine the onset of the liner patterned buckling phenomenon with the load displacement curve. Buckling of linerboards 42 lb/msf and lighter is observed to occur for C and A flutes prior to the load reaching the peak value where the sample fails by the formation of a crease as can be seen in the mirror image of the right hand shot. What does liner buckling mean for ECT?

Effects of Component Properties on ECT

$$ECT \propto 2STFI_{liner} + \alpha \, STFI_{medium}$$

Conventional Whitsitt model relates compressive strengths (short span STFI) of components to ECT, suggests an optimization strategy…

References: Seth 28, Whitsitt 14, El-Hosseiny 22, Nordman 44, Byrd 11, Nordkvist 16

But there's **more** to it:

An 1963 IPST report mentions a "McKee equation"- like approach to incorporate lightweight liner interflute buckling during ECT:

$$ECT \propto 2(STFI_{liner})^b (\sqrt{D_{MD} D_{CD}} / a^2)^{1-b}$$
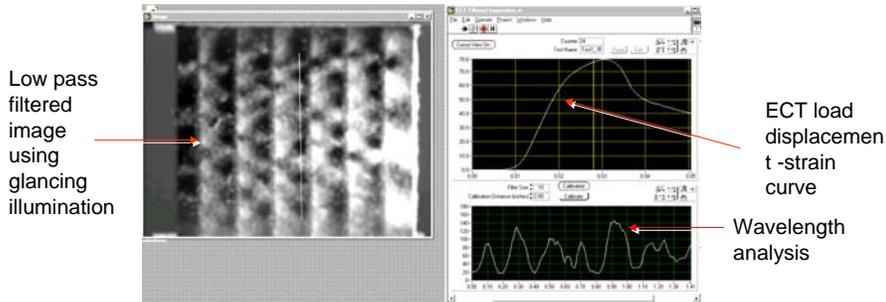$$+ \alpha \, STFI_{medium}$$

Notes (Buckling of linerboard facings during vertical compression):

The above equation says that the ECT value which is the compression strength per unit length of combined board is simply the summation of the compressive strengths of the linerboard and medium. Some will argue that replacing the STFI with Ring Crush may be relate better to actual box performance, some of these discussions are mentioned in the bibliography. This simple equation is good approximation but requires calibration of the proportionality constant which is around 0.7. What is says is that whatever increases the compression strength of the components will also increase the ECT of the combined board.

The simplest way to increase the STFI of linerboard for a given furnish is to increase the density through wet pressing. STFI increases with density in this case but at the expense of decreased caliper for a given basis weight. The decreased caliper of a linerboard greatly decreases its bending stiffness which then causes buckling of the liners at lower vertical loads.

How to incorporate the liner buckling that we see into the compression model for ECT? Let's apply the same thinking McKee did for the panel compression of a 4 sided box under vertical load. This leads to a "McKee-like" equation for ECT which has bending stiffness terms of the liners.

Liner buckling occurs in C and A flutes for linerboards 42# and lower

Low pass filtered image using glancing illumination

ECT load displacement -strain curve

Wavelength analysis

Result: **Predicted ECT's are slightly lower than expected from component compressive strengths for lightweights especially when the caliper is reduced too much to gain STFI !**

Notes:

When will liner buckling occur? Whenever the compression strength STFI of the liner is greater than the panel buckling strength P_{crit} of the liner, if we think of the liner as a plate supported between the glue lines separated by the flute spacing length a:

$$STFI > P_{crit}$$

where from elastic plate theory we can approximate the Euler buckling load to be related to the bending stiffnesses in MD and CD and flute spacing a:

$$P_{crit} \approx \frac{4\pi^2 \sqrt{D_{MD} D_{CD}}}{a^2}$$

For typical liners, the above equations predict and confirm the observation that buckling in ECT occurs in C and A flutes, sometimes in B flute but not in E flute.

The model for ECT with buckling can be used to determine the point at which further densification will not produce any further gains in ECT for a particular basis weight. For 20 lb/msf liner the limit in density is calculated to be 0.5 g/cm^3 (31.2 lb/ft^3), for 33 lb/liner the critical density is calculated to be around 0.7 g/cm^3 (43.7 lb/ft^3).

Investigations of effects of Cutting Methods

Sumitomo razor cutter along the MD
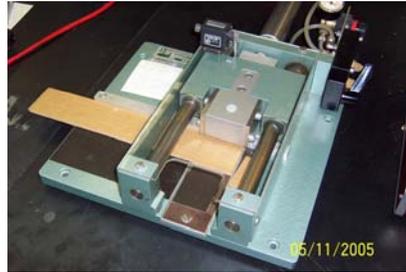
L&W Billerud style razor cutter for the CD, 2" x 2" sized samples

ECT requirements: failure mode must be compressive, no buckling or bending or edge compression , References: Nordman 50, Crisp 45, Kroeschell 4, Batelka 1, Koning 14

Notes:

A large section of the bibliography deals with the various techniques and methods to get a "true" measure of the compression strength of corrugated board. Considerable attention has been directed towards the method of cutting samples, the types of knives, parallelism of edges, etc. The aim is to obtain compressive failure in the body of the test specimen and not at the edges of the sample which may be the weakest point if they are not cut squarely and properly.

Shown above is a method to prepare samples for the clamp T839 method first cutting 2" strips along the flutes CD and subsequently using the two blade Billerud style of cutter across the MD to produce sharp parallel square edges that will contact the platens during compression.

ECT Methods: Clamp vs Neckdown vs Waxed Edge
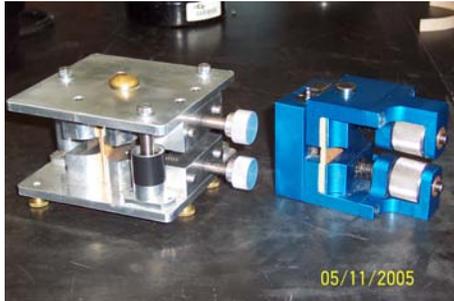
Sumitomo and Emerson ECT clamps, 200 grit sandpaper on jaw faces, 10 psi pressure from spring clamps.

References on T 839: Schampfer 10, 15, Eriksson 40

L&W neckdown ECT sample cutter, localizes compressive failure

References: Koning 23, Frank 38, Eriksson 40
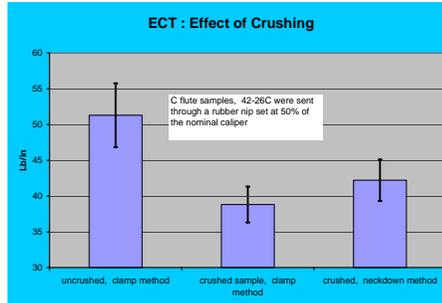

Notes:

The waxed T811 method which is the official method for Freight Classification requires a 38.1 mm (1.50") specimen height for C flute with its edges to be reinforced through dipping in wax to a height of 6 mm (0.25") leaving a free span of 26 mm (1.00"). More convenient and seemingly more popular as reported by the number of ECT participants in the Collaborative Testing program is the T839 method with 2" x 2" squares placed into a specified clamp as shown. Spring loaded clamps along with sand paper covered faces intend to immobilize the portions of the specimen that are clamped forcing the compressive failure and any out-of-plane displacement to the 0.43" free span.

When using the clamp T839 method, care should be taken to ensure that the tested specimens have an evident crease failure in the 0.43" middle free span section. Heavyweight board or high strength samples may demonstrate instead a compressive failure at the edges, alternatively, samples that have a lightweight medium (20 lb/msf or less) or have been subjected to out-of-plane crushing can demonstrate a delaminating bowing failure in the free span. In these cases, preparing the test specimens in a "dog-bone" or "neck-down" shape will concentrate the load stress in the center and produce a truer compressive failure.

Effects of method on ECT results, crushed samples

T 839 can have sample compressions along the edge, have to check samples after each test to ensure crease failure occurs between clamp faces
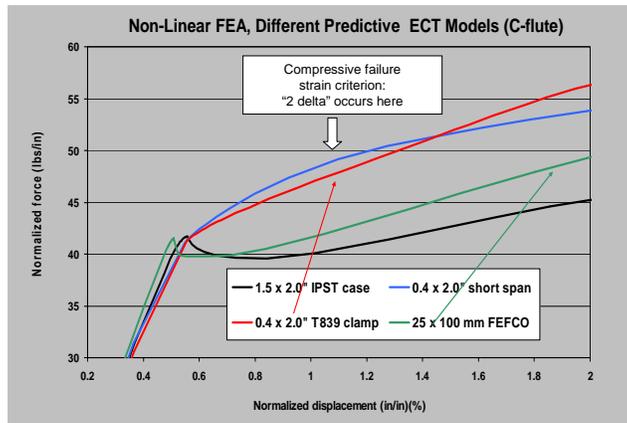
An example of ECT differences between crushed (50% of caliper) and crushed board and method of measurement

ECT : Effect of Crushing

C flute samples, 42-26C were sent through a rubber nip set at 50% of the nominal caliper

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Notes:

Illustrated above is an example several types of ECT tested samples. An edge compression is a rejected test. An MD crease across the sample in the free span is an acceptable test. In a crushed sample, there can be outward bowing of the sample and not a well formed crease. Note when a crushed sampled is made into a neck-down shape, a crease does form and a higher ECT value is obtained although this value is lower than for the same board not crushed.

Computer FE non-linear models suggest differences in results can be expected using different ECT methods

Non-Linear FEA, Different Predictive ECT Models (C-flute)

Compressive failure strain criterion: "2 delta" occurs here

1.5 x 2.0" IPST case — 0.4 x 2.0" short span
0.4 x 2.0" T839 clamp — 25 x 100 mm FEFCO

Normalized force (lbs/in)

Normalized displacement (in/in)(%)

Structural Mechanics group at Civil Engineering GT

• Hill's anisotropic plasticity constitutive model

• ABAQUS non-linear code

Note, the larger the free span, the lower is ECT

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Notes:

Ongoing collaborative work with the Structural Mechanics Group at Civil Engineering at Georgia Tech is producing a non-linear FE models using a modified ABAQUS package. Using elastic constants determined from IPST measurements for a typical 42# linerboard and 26# NSSC medium, the test geometry was altered in the simulations to produce the stress-strain curves shown in this slide. Compressive failure is not built into the model so strains exceed failure limits of the material as defined by the "Tsai-Wu" criterion but failure is estimated at the "2 delta" at about 1+ % strain coinciding with actual observed load displacement data.

Generally, a larger free span is predicted from the analysis to produce a lower ECT value since larger free spans allow a greater and more distributed out of plane motion which we see as buckling of the liners when the sample is placed under a vertical compressive edge load.

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A Close up shot of the ECT of Crushed C flute

Outward bowing failure of liners

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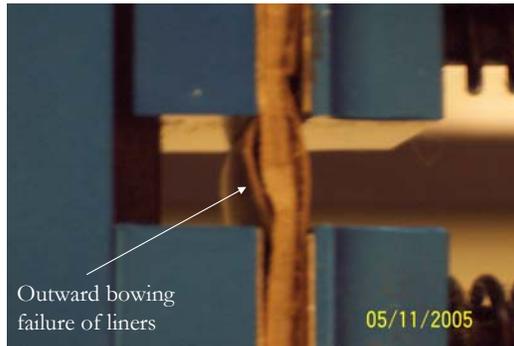
Crushed boards and lightweight A and C flutes (20# and lower) are susceptible to this mode of clamped ECT failure – get lower than expected ECT values when this happens !

Notes:

This is a close up shot of an ECT test of a crushed C flute board at its peak load. Notice how the samples is buckling in the free span and inside the clamps. The same effects can happen in test samples comprised of lightweight medium. The 10 psi of the spring clamps crush the weak board causing bulging in the free span which bows outward further when the vertical load increases during test.

Summary

- ECT is the main predictor of box performance: BCT and lifetime, 30 + years of literature

- Has the *potential* economic advantage over Mullen that it can be optimized without basis weight or furnish changes

- ECT is a failure test, so it is sensitive to sample preparation, sample type (flute size, medium basis weight, flat crush) and testing method …testers beware !!

Notes:

There is a considerable wealth of literature available on ECT, the attempt has been made to cover accessible articles that have been the most relevant to corrugated research at IPST.

ECT can be increased through increasing the compressive strength of the components which for a given basis weight is done comparatively easily through increased density by means of wet pressing, refining, draw tensions, furnish changes. However, as recent IPST research has shown, increasing density to obtain higher compressive strength without limit can be compromised by linerboard buckling.

In optimizing ECT in any grade development or quality control program, the values of ECT are dependent on the quality of board being tested and the test method. Care and vigilance must be exercised to ensure that the optimal ECT methods are being applied to obtain a valid estimate of the compression strength of corrugated board.