Technical Summary

Introduction

The Chalmers DST (Dynamic Stiffness Tester) presents corrugated board manufacturers and users with a very powerful tool to measure the quality of their corrugated board.

The Chalmers DST measures the MD Torsional Stiffness (Shear Stiffness) of a sample of corrugated board. Once the sample has been placed in the tester a result is returned by directly measuring the frequency of oscillation of the torsion pendulum. This test is very sensitive to the structure of the board and the condition of the fluted medium.

Fluting process

During the corrugating process huge forces are imposed on the fluting medium. Figure 1 shows the tensile forces that the medium has to endure. With recycled fiber mediums the sheet is soft enough for easy compliance in the fluting labyrinth and there is usually enough wax in the paper to act as a lubricant to lower the friction and prevent flute fracture. Semichem mediums are more prone to fracture because of higher stiffness and a lack of lubricant. Wax bars or allowance in manufacture can overcome this.

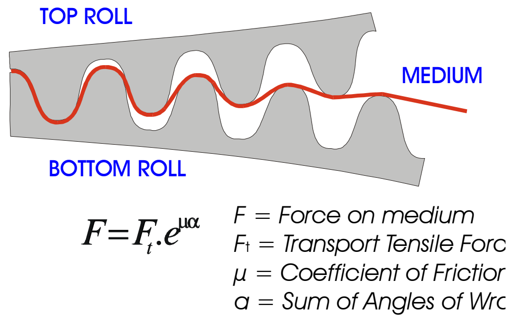


Figure 1: Tensile forces on medium in nip

The actual forces on the medium in the embossing zone are even higher than the equation shows because the medium gets wedged and comes to a stop just before full engagement of the embossing teeth. The tips of the flutes take the bulk of this effect. Intra-fiber bonding is repaired to a large extent by the emboss itself and the application of starch for the lamination of the liners. Figure 2 shows bad flute fracture on a semichem medium.

How well are you making your board?

- How much damage is occurring in your corrugating process?
- How well are the flutes being made on your corrugator?
- Are your fluting rolls worn out?
- What is the cross machine medium strength profile like?
- How well does your gluing process work?

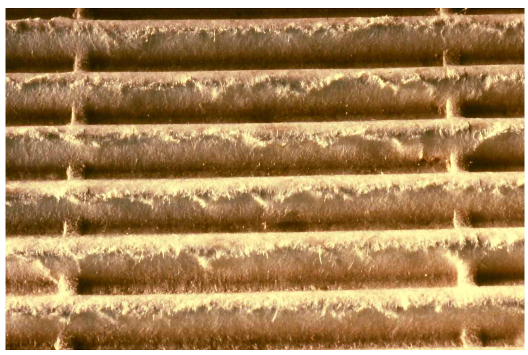


Figure 2: Fractured SC medium

Raw material quality is easily tested with Ring Crush, SCT and Tensile tests. But what about the quality of the corrugated board? Or your board after the printing and case making process?

Chalmers DST

Because this test is so sensitive to the structure of the board and the condition of the fluted medium it will give you the information you need to produce the very best board that your plant is capable of.

Some corrugating myths dispelled

ECT and BCT tell me how well my boxes will perform.

ECT tells you how well your supplier made the liners and medium not how well your boxes will perform. Flute damage occurs in the MD while ECT measures in the CD. There will be some loss in result with crushed board but ECT is not very sensitive to crush. ECT and BCT are closely related.

BCT tells you how well your boxes perform on a short term compression test not in a service environment.
Boxes do not fail under BCT conditions. If they are going to fail in a compression mode it is over time in the service environment at a much lower load than the BCT test will tell you. Cyclic humidity compression creep performance is a much better indicator of box performance in the service environment.

Caliper will tell me if the board is crushed.

A Caliper test will not tell you the full story. The board will be much more damaged than you appreciate because of springback and the relative insensitivity of caliper to crush.

Flatcrush will tell me the strength of the medium in the board.

Flat crush reveals more about the weight of the medium than its likely performance in a box.
Flatcrush is the compression resistance of the final collapse of the medium. The medium's performance as an engineering component of the corrugated board has long been destroyed at this stage. The final collapse is influenced by the medium's grammage but the difference in results of a badly crushed board versus a good board of the same material would not tell you the board had been crushed. Hardness is a much more reliable indicator for medium damage compared to flatcrush.

Corrugated board as an engineered material

Corrugated board can be modelled using Finite Element Modelling or more simply as a three ply sandwich material using classical lamination theory where board stiffness is proportional to the tensile stiffness of the two liners multiplied by the square of the distance between them. It is the medium's job to keep this distance constant to maximise stiffness. If the medium is damaged by crushing, the thickness is reduced but even worse in a buckling situation, bending forces reduce this thickness even more. The stiffness is reduced by the factor of the square of the reduced thickness divided by the square of the original thickness. When buckling reaches a certain point, the panel can no longer take compression loads, which then fall entirely onto the corners and the tertiary failure zone is approached.

The problem of using board thickness to measure crush and ultimately board performance is in the fact that the springback effect after crush on board is quickly absorbed on bending and the true thickness effect occurs. Bending stiffness is a much better test for board crush and likely performance than thickness, but MD torsional stiffness is an even better test for medium performance in the board structure.

In a corrugated box under compression in the service environment, torsional stiffness failure precedes bending stiffness failure which precedes compression failure which leads to box failure.

Technical Summary *Part 2*

Engineering for stiffness

Corrugated board is an **Engineered Product** and its bending stiffness depends upon the "I beam" effect where the stiffness is a function of the elastic modulus of the liners (tensile stiffness) multiplied by the caliper of the board squared. Most of the caliper, hence stiffness is provided by the fluted medium, see Figure 1.

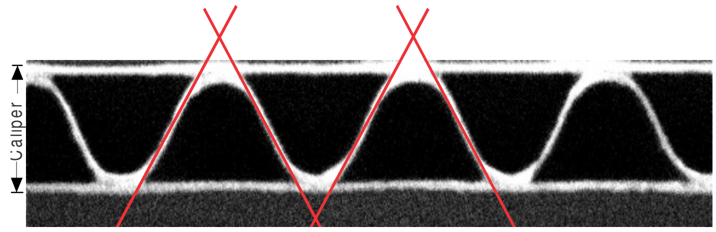


Figure 1: Fluted medium holding liners apart

This "I beam" method of obtaining stiffness is commonly used in engineering design. In conjunction with the "I beam", a triangular form is often used to provide the caliper part of the design. Triangles serve the dual purpose of providing diagonal bracing along with the spacing required to multiply the stiffness effect of the outside liners, plates or whatever. A really good example of triangles and the I beam effect to obtain stiffness is seen in Figure 2 where the stiffness of the railway bridge is a function of the steel triangles and the top and bottom plates. Engineering wise, there is not too much difference between the equations for this bridge and a piece of corrugated board.

The triangular shape offers both excellent light - weight separation of the outside plates (liners) as well as bracing against shear (sliding) movements of the plates that can lead to instability and damage to the bracing elements themselves.
A pure triangular shape with straight flanks is the best for stiffness as compression forces are then channeled straight down the flanks which minimizes premature buckling of the flanks and failure of the structure to provide the required stiffness.

Figure 2: Railway bridge showing triangles and I beam

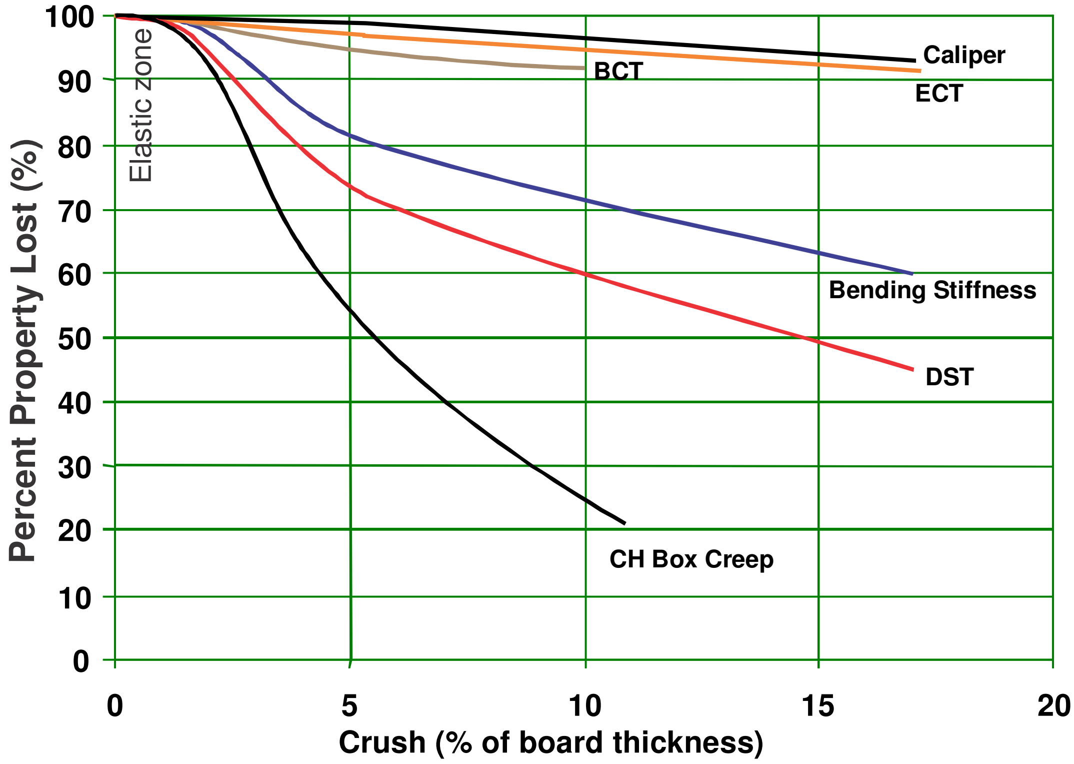
Unfortunately corrugated board fluted medium is not a pure triangle and it would be very difficult to make it this way, so we have to put up with compromises which we more often than not make worse by poor manufacturing techniques, lack of maintenance and poor selection of component grades.

MD Torsional Stiffness as measured by the Chalmers DST is the quickest, most accurate and reliable method of measuring the bracing quality of your flutes and thus the" in service" performance of your boxes.

By making sure that we are getting the most out of our fluted medium we can then look at reducing the weight of the liners. This is because the liners are very likely to be heavier than required to allow for underperforming damaged medium. Most boards can use liners one or two grades lighter than currently being use. This is big money. If you are looking at sustainability and light-weighting then medium performance is vital for corrugated board performance.

Summary of property versus crush results

The figure below shows how corrugated board properties are effected by board crush. This data was obtained as part of a huge study between Visy Board and NZ Forest Research Institute (PAPRO) in 2006.



At 10% crush the Caliper is effected by about 3.5%, the ECT by 5%, the BCT by 8% the Bending Stiffness by 28%, the MD Torsional Stiffness by 40% and the Cyclic Humidity Box Compression Creep (CHBCC) by 75%. The BCT data finished at 10% crush but we believe that the line may trend more steeply down after about 12% crush.

CHBCC is a box stacking test where the load is kept constant and the humidity varied between 50% and 90% in 12 hour cycles. This test is severe but far better related to box performance in the service environment than any other test. Unfortunately it is very expensive and time consuming to perform and very few laboratories can do this.

CHBCC facility at PAPRO

However the **Chalmers DST** is closely related to CHBCC performance and can be used to predict stacking performance in the field far better than any other standard test carried out in packaging labs.

Technical Summary *Part 2a*

Chalmers DST and Box Stacking Performance

Looking at the chart of Percent Property Loss versus Crush on the back side of Technical Summary Part 2 we can see how typical corrugated board properties are effected by board crush. This summary takes these results one step further.

In the Science Summary we showed the relationship between crush and DST and why Caliper is not a reliable indicator of board crush. We have also mentioned that an Empirical model is available from Korutest to predict what the BPI should be using different grades of medium and board construction weights.

If the board is well made and not crushed during conversion into boxes then the box will have the maximum stacking strength it will ever achieve and all its other properties as in the chart mentioned above will also be maximised. However if the board is not well made or crushed as determined by the Chalmers DST then you can expect a degradation in box performance and perhaps failures as shown in Figure 1..

Figure 1: Collapsing stacks in high humidity storage environment.

The DST result can be normalised between grades by comparison with the Korutest DST model or some other internally recognised standard value and utilised as a **PERFORMANCE INDICATOR or DSTpi**.

Some companies call this type of performance factor a Key Performance Indicator (KPI) and rate various plants grade by grade, between plants and over time on the outcome of this performance indicator.

For an example of how to use a performance factor say the Korutest model predicts a bpi of 13.0 from the components used (say 176/142RF/176 ISO or 36/29RF/36 USA) and a DST result of only 7.8 is achieved then the Performance Indicator is:- (100* 7.8/13) = 60% DSTpi

This DSTpi can be used within **corrugating plants** locally, nationally and internationally as a comparative measure of how a particular plant is performing. Samples need to taken from printer feed stock and printed and unprinted areas of the final job. These figures will show how much crush is attributable to feed rollers and plate pressures. An example of how to treat this data in a corrugating plant is shown in Figure 2 where DSTpi for a typical board grade is plotted against time.

This DSTpi can also be of great value to the **purchaser of corrugated boxes**. As a packaging client you want to make sure your supplier is sending you good boxes that have not been compromised in the box makers process. Table 1 shows typical results for one grade of box supplied to a packaging user for transport and storage of goods for a final Supermarket customer.

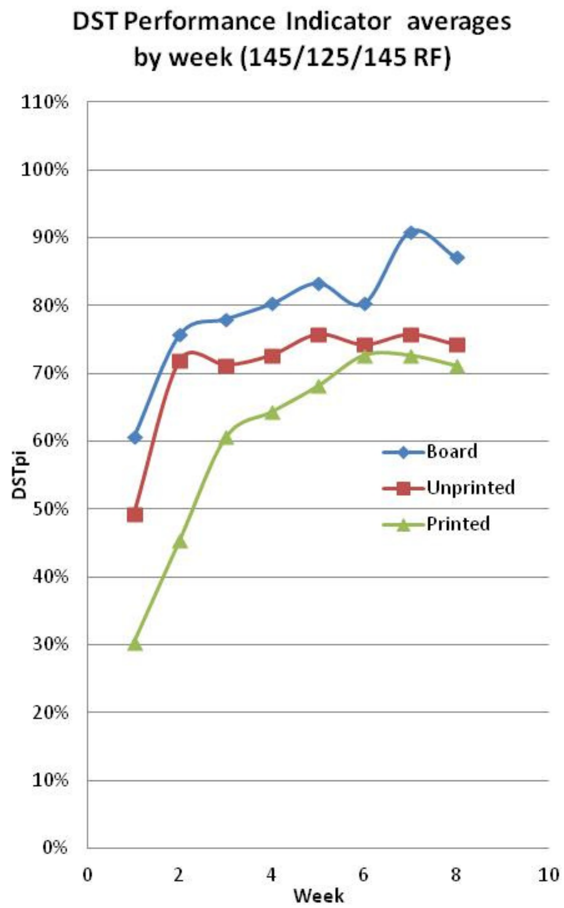


Figure 2: DSTpi versus time for a typical grade.

Table 1: Results of DST tests on boxes supplied by three different box makers.

Board grade 145/125/145 RF
Model result 13.2 bpi
All results in DSTpi (%)

Supplier	Unprinted	Printed	Average
DSC	50	29	39.5
CBC	72	62	67.0
ABB	95	92	93.5

Bearing in mind that all the boxes are made from the same paper grades, which supplier would you choose to go with?

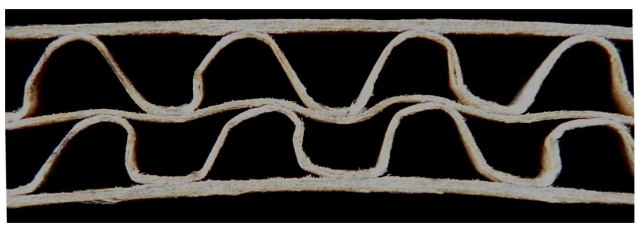


Figure 3: MD Torsional stiffness fails then bending stiffness fails.

The huge spread of results on this page is typical of what we see in the market place between suppliers and even from the same plant on different jobs. If you do not measure a property, how can you control it?

MD Torsional Stiffness as measured on the Chalmers DST is the most likely property of a corrugated board to be compromised by poor manufacture or crush damage, see Figure 3. Caliper, ECT, FCT, BCT etc are not very sensitive to this property and unfortunately MD Torsional Stiffness is the basic property that under load, starts to fail first. Then bending stiffness fails and we end up with bulge leading to compression failure and ultimately box failure.