Box Crush Test and the Chalmers DST

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Summary

BCT can be predicted from paper properties and box dimensions but only for undamaged boxes.

Crushing corrugated board lowers the boards MD Torsional Stiffness (MDTS) which is the most sensitive structural property of corrugated board. Failure of MDTS leads to bending stiffness failure which leads to box bulging which leads to compression failure which leads to box collapse.

With enough test data, the BCT for any one box type can be predicted from MDTS with the uncrushed highest MDTS box having the highest BCT.

Because the BCT of a box is reliant on box dimensions etc, MDTS cannot be used alone to predict BCT and data from different boxes should not be mixed without careful consideration.

The Chalmers DST is the fastest and most accurate way to measure MDTS and can be used at any point of the manufacturing process for speedy QC.

Did you ever wonder why your hand made box samples were always better for BCT than the production result?

What makes BCT?

Where does a box get it's BCT from?

It has been shown by McKee et al that the BCT of a box can be largely predicted from the components used to make the corrugated board, the flute type and the dimensions of the box. The Ring Crush test (RCT or SCT) of the components can give the ECT result which can be used (McKee) to estimate the BCT, see below.

ECT and BCT can be calculated from paper components using the sum of the RCTs of the components and the McKee Equation. This should be the best result obtainable from the components used.

. ECT = k(RCT L1 + RCT Med xTUF + RCT L2) TUF = take up factor
. BCT = 5.87 x ECT x √Caliper x √Box Perimeter kN (McKee)

Neither of these formulas incorporate a factor for how well the board is made or treated.

The 'Structure' is ignored and McKee warned that the equation may not apply if boxes had fabrication defects such as crush, low flat crush, leaning flutes or poor adhesion. Also the height of the box is not considered. The caliper in this case is largely the measure of the flute type rather than the crushed board thickness. One of McKee's original equations used the square root of the multiple of the md and cd bending stiffnesses which would be affected by crush but these stiffness are very difficult to measure and caliper was substituted to make easy use of the McKee equation possible though accuracy was lost.
The answer to the last question in the summary about samples versus production boxes is that hand-made samples are simply cut and formed without the crushing effect of feed rolls or printing plates. The Chalmers DST will quickly show you the difference.

BCT versus Board Crush

It has been shown many times that boxes made from crushed corrugated board do not perform as well as boxes made from uncrushed board. In the Oct 1989 Paperboard Packaging Journal, Joseph Bick presented a paper called "The Cost of Crushing Flutes is High". Figure 1 shows Bick's data where BCT compression loss and the increase in paper costs to allow for this BCT loss are plotted against percent board crush.

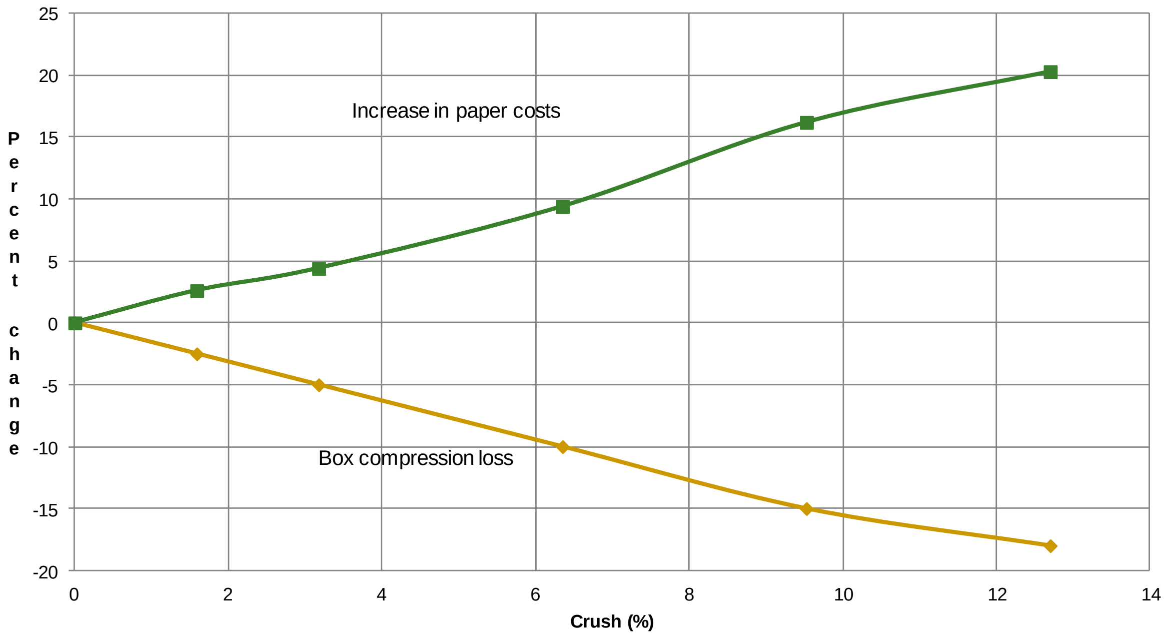

Figure 1: Bick's data of BCT and paper costs versus percent corrugated board crush.

Bick also made the comment in his paper that "Crush is difficult to measure and commonly understated".

Chalmers (Appita Journal Sept 2007) also showed that board crush adversely affects BCT but also has a far more dramatic effect on performance in the service environment as simulated by constant compression under a cyclic humidity environment. Figure 2 shows BCTs and cyclic humidity performance of three corrugated boxes made from uncrushed board and two levels of crushed board. The degree of crush is measured by Chalmers DST bpi levels (MDTS). On the left hand side of Figure 2 are the cyclic humidity performance curves where for example if the box has to sustain a 80 kg weight in the service environment the uncrushed board (bpi = 24) would last for 40 cycles, the board crushed to 21 bpi would last 15 cycles and the box made from the board crushed to 14 bpi would only last 8 cycles.

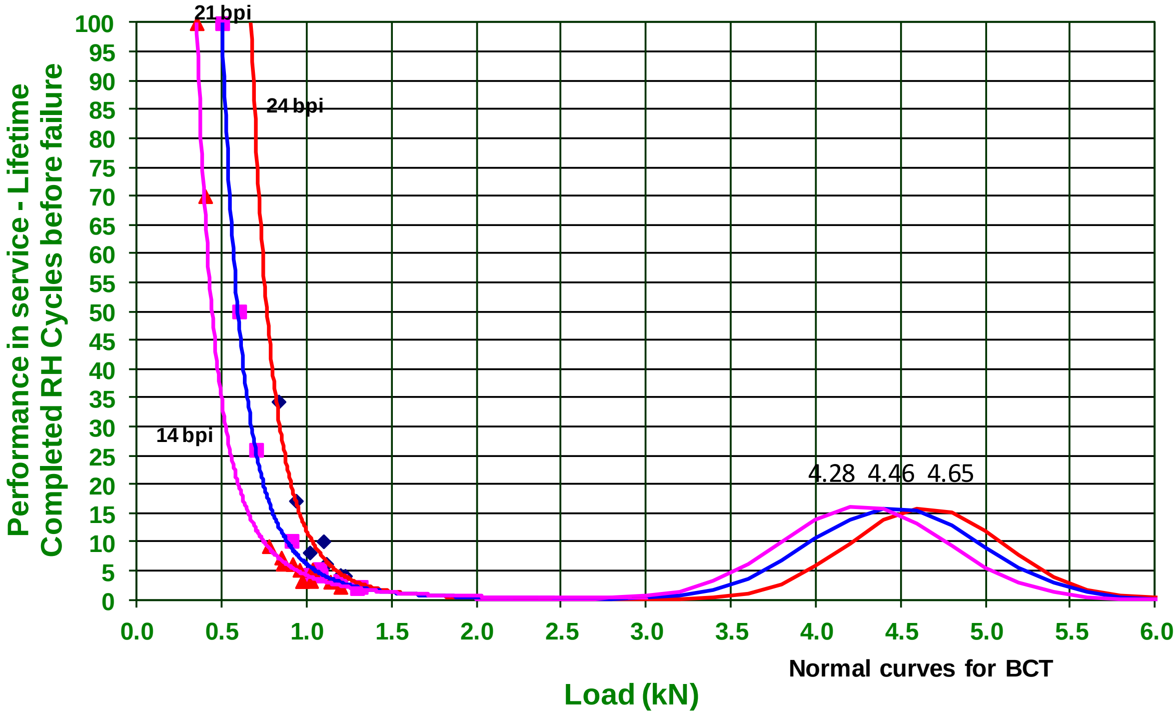

Figure 2: BCT and cyclic humidity longevity results for 3 levels of board crush. Uncrushed board (24 bpi) had a BCT result of 4.65kN while the most severely crushed board (14 bpi) had a result of 4.28 kN.

What has definitely been shown over the years is that uncrushed board gives the highest BCT level that the components and manufacturing equipment is capable of at the time of manufacture. There are many ways to improve the quality of the manufactured boxes and that is usually achieved in two stages by eliminating crush during conversion first then optimising the processes on the corrugator to make stronger board off the corrugator.

BCT testing unfortunately has many problems in its implementation. The major problem is the large standard deviation of the results and the time and resources required to try and minimise this figure. Boxes have to be pre-conditioned at about 30% RH then conditioned to 50% RH. This takes a lot of time and space and can only be done in conditioned laboratories. This is not suitable for online QC as the boxes are usually long gone before the results are obtained.

But even on well conditioned samples the standard deviation is still high and many boxes are needed to be 90% sure of the final mean result.

DST on the other hand is very quick and reliable and you can guarantee that for any box design that if the board is made well and not crushed as measured by the DST then the BCT of that box will be maximised. Once you start crushing as measured by the DST your BCT will be heading down.

Why is BCT not as sensitive to crush as cyclic humidity lifetime performance? All cellulose fibre products are subject to creep when under load (compression or tension). This is a time dependant property that is made worse in corrugated boxes by cycling humidity. Damage to the structure of the board by crush significantly speeds up the creep process. BCT on the other hand is a short time test that has very little creep component. The faster you do your BCT test, the stronger the box will appear to be. Long term stacking tests using deadweights in a controlled atmosphere will show significantly reduced results compared to the BCT because of the creep effect only.

What happens when corrugated board is crushed?

Figure 3 shows the relationship between caliper, MDTS and corrugated board crush using 29 sample pieces of board from the same sheet. The pieces were crushed to different levels in a machinist's vice as indicated then caliper and DST measured after 3 hours. Curves obtained like this can also be used as a calibration on any board to give the absolute crush level.

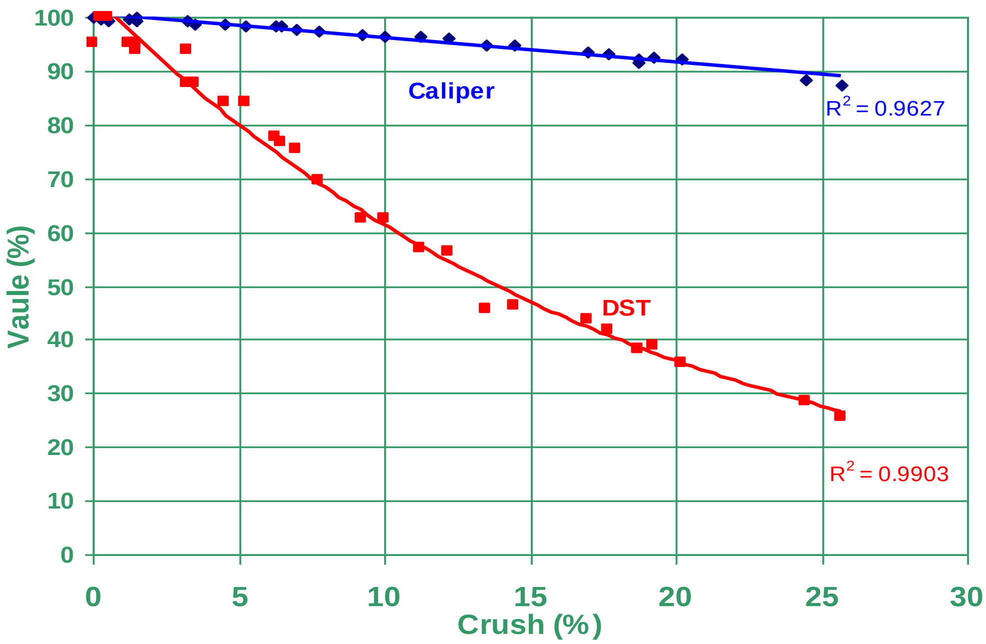

Figure 3: Caliper and MD Torsional Stiffness (DST) versus corrugated board crush

Figure 3 shows how DST is much more sensitive to board crush than caliper. In fact MDTS is one of the most sensitive properties to board crush. MDTS is also sensitive to the quality of the fluting process and the materials used.

Figure 4 shows the ECT results (FEFCO) for the same 29 samples used in Fig 3.

Caliper and ECT are commonly used in corrugating plants to measure crush but figures 3 and 4 show that while Caliper has a good relationship with crush (in strict laboratory conditions), the sensitivity is very low. ECT has a very poor relationship with crush which is understandable because we are damaging the board in the "Z" direction then testing it in the "X" direction.

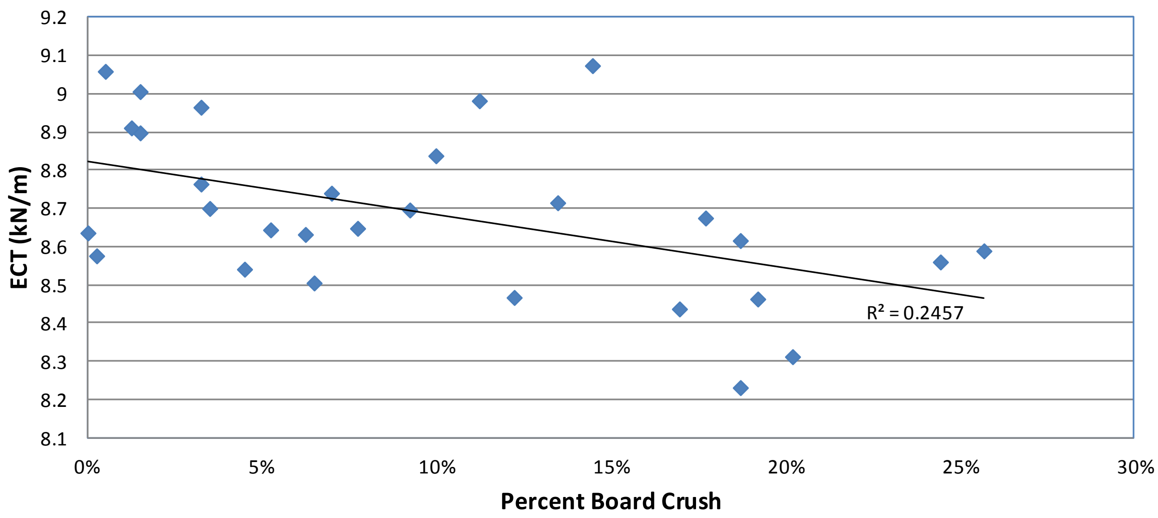

Figure 4: FEFCO ECT versus percent crush for 29 pieces of board on the same corrugated board samples as Figure 3.

When corrugated board is crushed the engineered structure of the board is damaged. This structure is quantified by MD Torsional Stiffness. So crushing damages MDTS and the other property effects are as a result of this loss of Torsional Stiffness. Caliper loss is often regained on standing but the Torsional Stiffness can never return to previous levels.

Can MD Torsional Stiffness be used to calculate BCT?

Figures 1, 2 and 3 show very strong relationships between board crush BCT and MD Torsional Stiffness. So yes MD Torsional Stiffness can be used to estimate BCT but only on a box by box type basis. Every box will have its own BCT vs MDTS relationship depending on flute type and box dimensions. So you can not develop an accurate single model for BCT vs MDTS unless you have a very powerful "Finite Element Analysis" model then tested on a huge database that incorporates many material properties and box design criteria. It may be possible to obtain enough Empirical data to factor in MDTS into McKee's BCT equation. But whatever the outcome, with all things being equal, the box with the highest MDTS will always have the highest BCT.

The MDTS can be considered to be a degradation factor where the percent loss in MDTS compared to best attainable will predict a boxes BCT. The factor may not be linear.

Crush versus board and box properties

Figure 5 shows a summary of how corrugated board crush effects board and box properties. The least affected property is caliper and the most affected property is box compression performance in the service environment as simulated by cyclic humidity compression creep testing. The best property to measure crush received is MDTS which is the most sensitive property effected by crush.

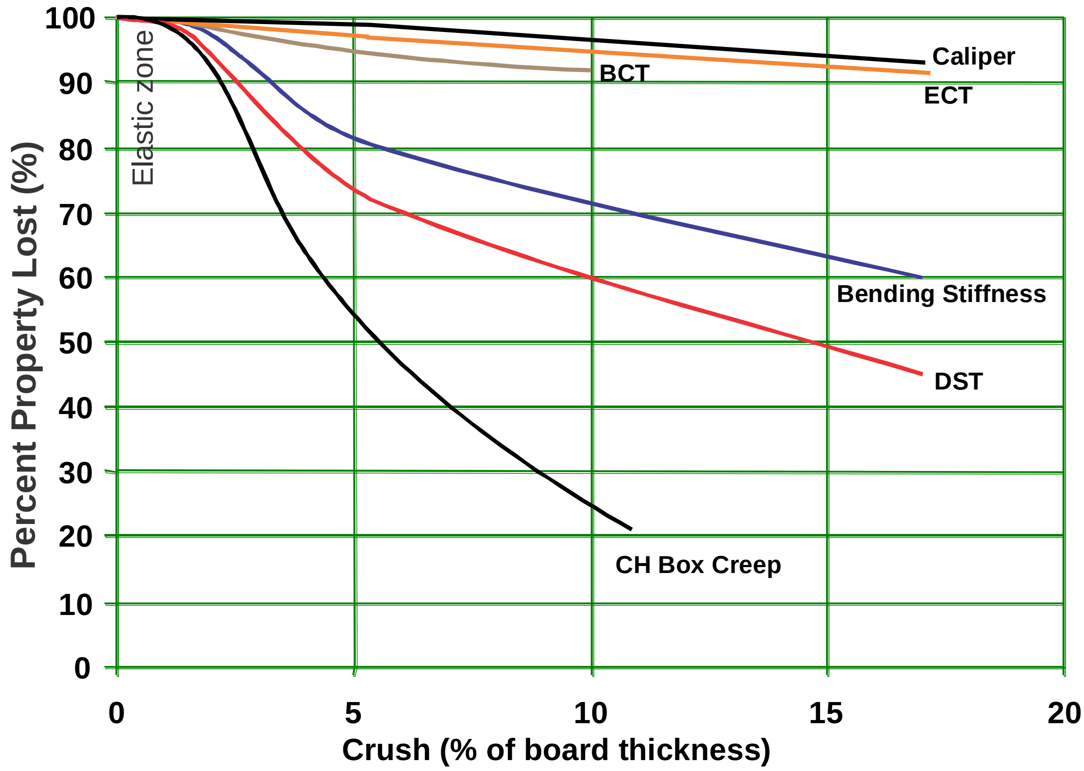

Figure 5: Percent crush versus board and box properties from Chalmers (Appita 2007)