

Development of a new measurement for board performance.

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Abstract

There are many issues that affect the ultimate performance of corrugated packaging in the logistic chain. One area that is attracting increased interest from box makers and box users alike is the benefit available from taking care during the corrugating and subsequent conversion processes.

Until recently, the damage attracted by the corrugated medium during conversion was poorly understood. Measurements developed specifically to reflect the resulting board performance were tedious and required interruption to the manufacturing process. Due to the spasmodic nature of these measurements enthusiasm for the measurement and real time control of box performance has been hard to sustain in the box making industry.

It is now known that up to 30% of the potential box strength can be lost in the box production process through a lack of care during manufacture and conversion. Such a large variation in box performance originating from the inability to control manufacturing quality is disturbing. However, it is only when the affect of these variations are translated to the field performance of the box that the magnitude of the problem becomes truly apparent.

In severe environments, with only moderate loads, a 30% variation in box strength may convert to a 100 fold change in the survival time of corrugated boxes in service. A case study is presented to emphasise the importance of damage control in the box plant.

The relationship between cost and performance is developed through the paper and it is demonstrated that, with proper care, large savings are possible in both cost and raw materials for a given application.

The remainder of the paper is directed towards the description of a new technology currently available to the industry developed to allow convenient spot checks of corrugated board performance (in a low-cost, hand held format) and a description of the complimentary, continuous, on-line technology that has developed from the initial studies.

These measurements are having a significant impact on the overall cost effectiveness and performance of both the packaging and corrugated board's ability to adequately survive the packaging chain.

Background

Corrugated packaging has been used to fulfil many freight and transport packaging applications for more than 100 years and, despite the many innovations and developments applied to the industry, little has changed in the overall design of the packaging structure since its inception. Then, as now, the packaging (and the packaging manufacturers – the box makers) are viewed with considerable suspicion by box users. Such suspicion is, sometimes, not warranted. However, the general observation that corrugated packaging has highly variable performance and is not “predictable” appears to be universal and has its basis in fact (1,2).

In the last 70 years (after a particularly spectacular failure leading to insurance claims) development of corrugated packaging based on guaranteed performance was put on hold and packaging was specified in terms of a minimum weight of the components and a burst value (fibre quality specification). Over time, due to the variability in materials and the lack of control in process and conversion it would be fair to say that paper corrugated packaging has been well over-specified in most packaging applications.

In the last two decades a performance specification has been introduced to allow manufacturers and users to minimise cost and weight and specify packaging based on acceptable performance for an application. Unfortunately, the industry has generally not been able to control its process variability well enough to provide certainty of performance to box users and most packaging remains over-specified by 30 to 50% (3).

Table 1 shows an estimate of the source of corrugated box variability and its magnitude (4). In this paper only the box related issues that occur due to poor box manufacture process control and measurement, and more specifically damage to medium performance, will be addressed. In each entry the typical range of variation attributable to each area of concern is given. Not all of these areas occur at the same time, however, often they are concurrent, and mostly they have independent and cumulative effects.

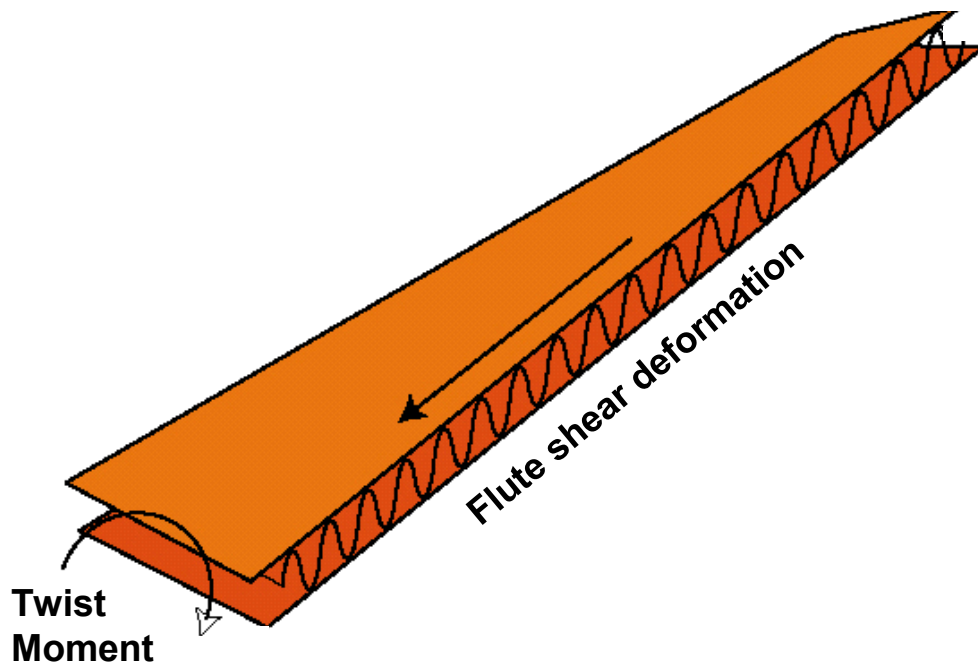


Figure 1. MD Shear twist test.

Table 1.

Cause	Attributable Loss (%)	Cumulative Retained Box Strength (%)	Survival time* (days)
Potential	0	100	1000
Paper variability	30	70	40
Panel damage	30	50	2
Crease damage	30	35	0.5
Transport	20	28	0

* Cycling high humidity environment

Shear Stiffness in box performance

In the late 1980's, Amcor Ltd in Australia, developed a sensitive bench test for the measurement of medium shear stiffness. The shear stiffness of the medium reflects the performance of the medium and corresponds to a level of performance of the corrugated board as a whole (5,6). In the Amcor test a strip of board is carefully cut from the made up corrugated board and placed in torsion through a known angle (See Figure 1).

The forces produced are used to determine the ability of the medium to resist changes in the flute shape when box panels are stressed. This has been found to be important in general box failure and the propensity of box panels to bulge or sag under load.

Such a test is more able to reflect the loss of board potential than say, traditional measures of crushing such as thickness. Much work has been done to show the poor relationship between thickness and board loss (3) and it should now be fully recognised that at the point where thickness differences in the board cross-section are measurable, between 10-20% of the board performance (BCT) is lost.

Figure 2 shows the relationship between corrugated board thickness loss due to crushing, a shear stiffness measure of the corrugated board, and box performance. Apart from the inadequacy of the thickness measure (most of the US box manufacturing industry still use thickness as a de facto damage measure (7)), it is clear that significant losses in board performance (box strength) are apparent with only a small decrease in apparent thickness.

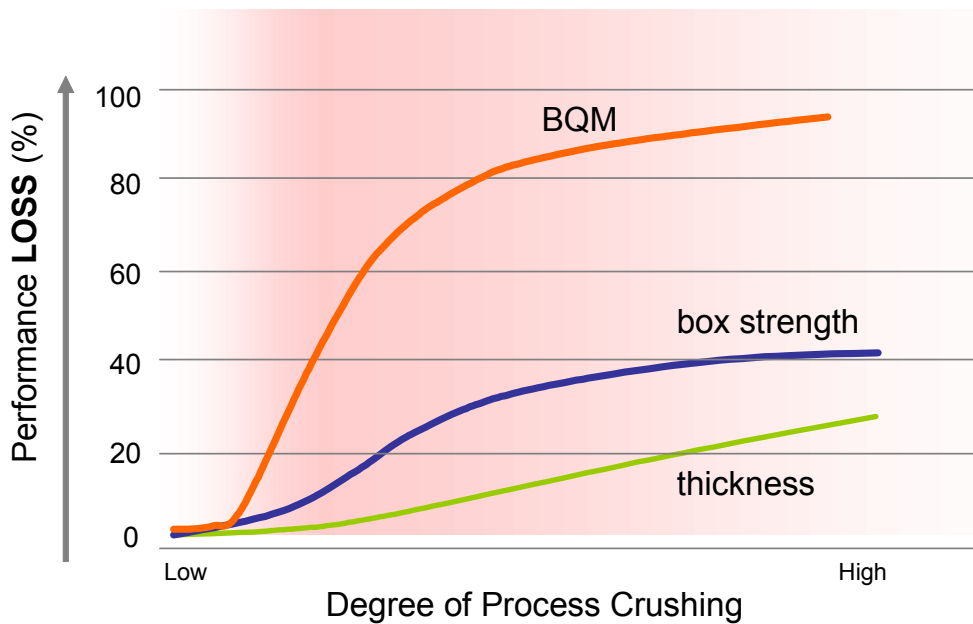


Figure 2. The effect of crushing on BQM (shear stiffness), box strength and board thickness (caliper).

Although the shear stiffness measurement has been used for two decades within Amcor Ltd, the measurement has not become a general specification employed through out the industry; despite its potential to save up to 30% of the box weight (read cost). The reasons for this lack of uptake are varied, but include the proprietary nature of the original Amcor measure, a lack of understanding of the technical aspects of corrugated board performance and the inconvenience of removing boxes and sampling in the box manufacturing process.

An additional difficulty is the “smearing” effect shown by taking a sample of board over a 200 mm length. In C-flute board this sample size means that nearly 30 flutes are included in the test. Damage events or areas, or individual flute damage tends to be blurred by these large test sample sizes.

To meet these limitations, a new test has been developed by XQ innovations P/L. The test applies a varying vibration of a certain mode and frequency, to the corrugated board and determines the natural frequency of the fluted structure. This natural frequency is strongly related to the shear stiffness of the core of a multi-component board (8,9). Figure 3 shows a set of resonance peaks that represent various corrugated board shear stiffness values.

Impact of medium damage

Previously the impact of medium damage on corrugated board performance and strength has

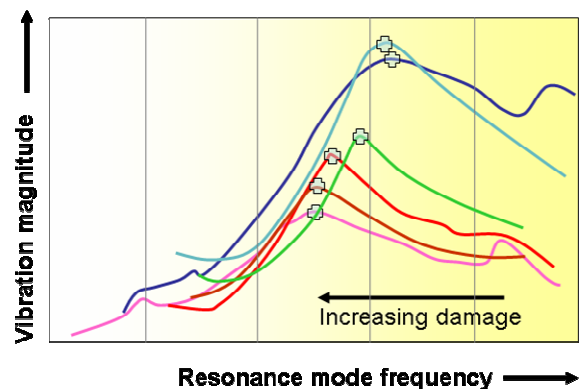


Figure 3. Peaks represent resonance points in a vibrating corrugated structure.

shown that diminishing board core shear stiffness can lower the box strength by up to 40%. Even quite moderate crushing will lower box potential by 10% or so (10). The real impact of induced manufacturing medium damage is seen when one explores the impact of corrugated performance loss on field performance.

Field performance is generally viewed as the fitness of the packaging to contain, ship and support the product from packing to its ultimate destination – either in domestic logistics chains or the more severe export chain.

Often boxes are required to withstand severe environmental conditions during their time of service and this can take the form of changing

temperatures, humidities, vibration and shock events. Depending upon the application, the time that a box must support loads and the load itself when boxes are stacked on pallets may vary. It is the effect of medium damage on stacking survival time that is most disturbing.

Even as far back as 1960 it was known that the relationship between stacking survival time (the time under a given load for the box to fail) and the load applied to a given box strength was very non-linear. In general terms an increase in applied load or an equivalent decrease in box strength for a given load will exponentially impact the survival time achieved. (11,12).

Figure 4 shows the shape of such a performance curve. It can be clearly seen that the survival time of a box under load is strongly, but non-linearly, dependent upon the box strength.

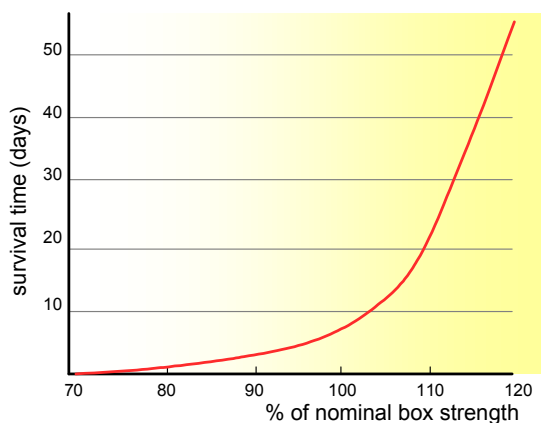


Figure 4. Generic relationship between box strength and survival time.

To make matters worse, the field environment may further diminish the performance of boxes in service with high humidity and changing humidity providing the worst cases as shown in Figure 5.

Typically, a loss of only 10% in box strength will halve the survival time in a cold room high humidity environment and struggles to provide one sixth the survival time in cycling high humidity environments. This is a very large variation indeed and, if medium integrity is not maintained in the manufacturing and delivery process, will be observed as huge variations in box quality by the end user. Of course, if the board strength variation due to medium degradation is even greater than 10% (30% is not uncommon) the non-linear response in stacking survival time will be much greater.

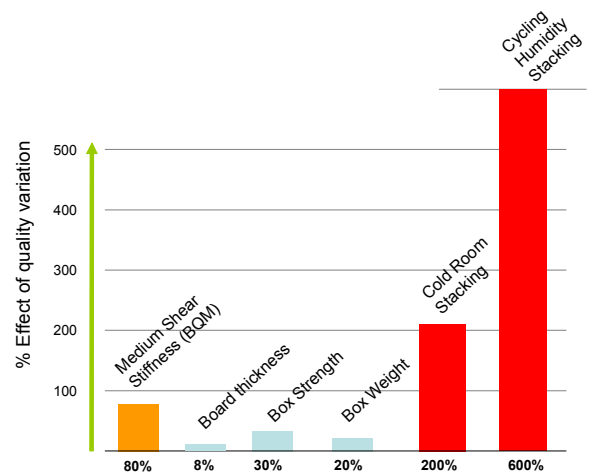


Figure 5. The impact of medium shear stiffness loss various box and field performance parameters

General box strength and stacking strength are not the only areas that are affected by poor medium care in manufacture. Tray sag, transport damage (4) and automatic erection machinery are also negatively affected.

In the case of automatic box erectors and packers, if too much crushing occurs around the vertical creases (apart from its very large affect on box strength and survival time), the weaker board areas will be prone to false creasing when the box is erected.

Evidence to suggest that extended damage around the load bearing creases does occur in practice is presented in Figure 6 which shows the shear stiffness of individual flute lines for a number of unused commercial boxes. Damage around creases is to be expected however the extent of damage away from the crease appears to vary greatly depending on the box design and the care taken during converting. As Table I notes, damage areas extending away from the crease (say above around 2 flutes distance) can and will have a serious effect on the ability of the box to maintain panel stability and withstand stacking load. The effect of crushing during printing can also clearly be seen in Figure 7. In this case, for a produce tray, due to the box maker's company logo.

The plot in Figure 7 shows the BQM levels as the measure moves in the machine direction across a box load-bearing panel away from the vertical box creases. In general terms the damage around the box crease extends up to 6 flutes (40 mm) from the crease and will markedly affect the performance of the box.

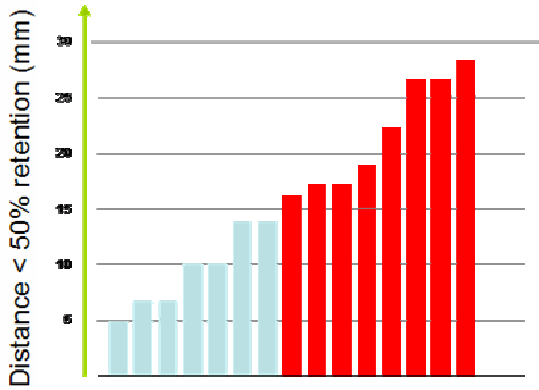


Figure 6. Crease widths (damage > 50% board retention) for a range of commercial boxes

Meaning

Figure 6 shows a range of tested boxes representing 15 different designs and “brand” customers with the distance damage extends away from load bearing creases. Significant loss in performance beyond around 15 mm from the crease is deemed to be unacceptable and should be engineered out of the package at the manufacturing stage. For the unused boxes tested it can be seen that over 50% have damage that extends beyond the acceptable level. As the crease “width” increases, these boxes will rapidly lose load stability performance further increasing the level of variability occurring in the field. The natural response to this manufacturing variation is to inflate the weight and cost of the package to ensure that all boxes meet the required field performance.

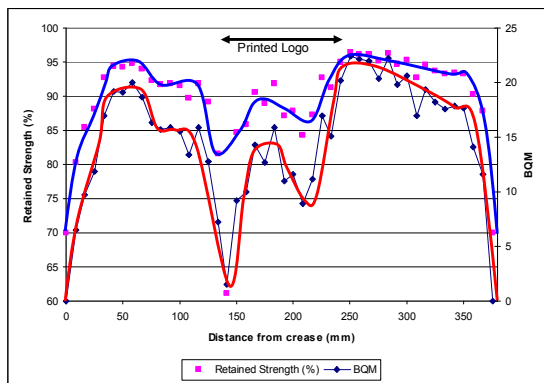


Figure 7. Damage profile across a box manufacturer's logo print.

In produce packaging, trays are often designed to provide adequate stacking and to ensure that base sag (the bottom of the tray) is not great enough to contact fruit or vegetables in the tray stacked directly below. Contact between the tray and the

produce would bruise and damage, what is quite often, valuable product. This is especially important in export markets.

XQ innovation have developed a measure that simply and accurately determines an important structural property of corrugated board. Some users of corrugated packaging report that there are very few failures in the field, and that often these are related to specific incidents that are out of the normal operating boundaries of the package's experience.

If this is the case, then it would be fair to say, given the new understanding of run of mill packaging corrugate quality, that nearly all corrugated box packaging is over-specified. Given the observed level of performance deterioration typical throughout the industry, over specification is the only explanation that would account for the lack of observed performance-failure in the field. Alternatively, one can view this certain over-specification within the industry as a direct expense met by the box user.

Interestingly, the potential for lowering board weight brought by this technology also favours the manufacturer –through the introduction of cheaper materials (recycled papers for example), the lessening of performance claims and the increase in speed on the manufacturing corrugators due to faster drying of the light-weighted board during the manufacturing process. It is the author's contention that around 10-15% of the cost of current corrugated boxes can be removed with accompanying consistency of performance.

Case Study I – Produce Tray

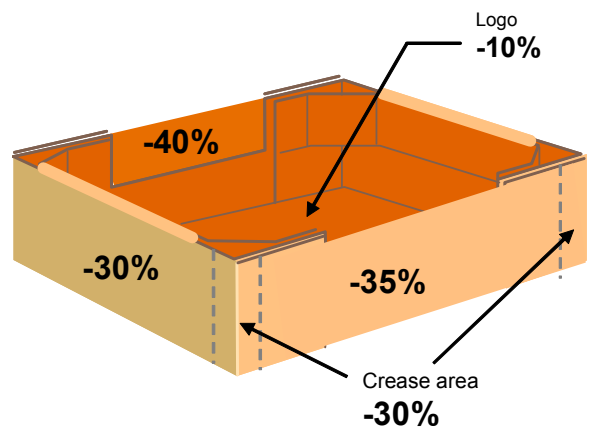
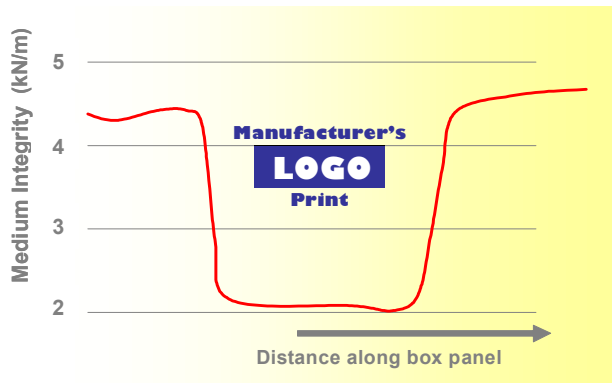


Figure 8. Stylised produce tray showing estimated BCT loss in panels due to process damage during manufacture.

As an example of the contribution that poor control of medium performance can make measurements were made of an unused field style mushroom tray blank to determine if significant variation in board

In the centre of the base panel printing the box manufacturer's logo dropped the BQM value by a further 25%. Figure 9 shows the damage profile across the logo.



In this particular case, the most damage occurs in the side walls that are being asked to support the major part of any stacking load. It would be expected that the box performance would also drop in line with the BQM value.

The other major structural area of concern is the damage around the vertical creases in the case of the tray wall performance and the base creases in the case of base sag performance.

Figure 9. Damage profile attributable to box manufacturer's logo.

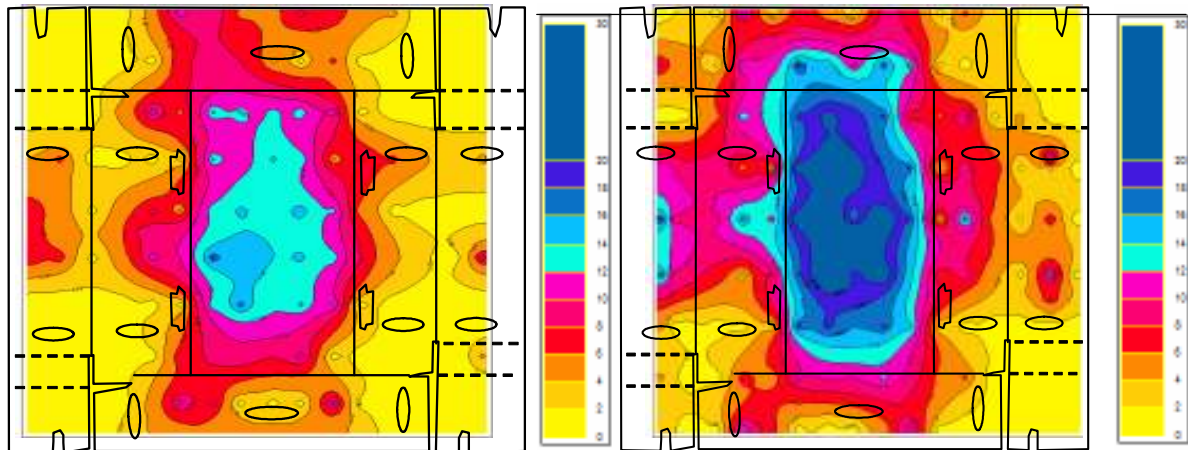


Figure 10(a)
Figure 10. Contour mappings of Mushroom box showing the board strength retention of (a)

Figure 10(b)
recent delivery (b) older delivery. Red/yellow colours are highly damaged areas.

performance (specifically due to conversion damage) was present. Figure 8 shows that in broad terms a BQM loss equivalent to 30% loss in board performance¹ was measured in the tray side walls, compared to the undamaged levels of the box. The damage is attributed to the heavy, uncontrolled print process. Additional losses in the un-printed walls causing a lowering of the board performance of around 10-15% was also measured attributable to the creasing and slotting process.

Finally, because the new measurement method lends itself to fine resolution measurements of medium integrity (BQM) it is possible to generate a contour map representing the medium damage developed across the blank. Figure 10 shows such a damage map generated for the mushroom tray using the BQM technology. In this mapping hot colours (yellow and red) represent areas of high damage and blue and green colours represent areas of lesser damage. The technique is particularly useful when the blank design is overlaid on the contour map as it becomes clear which box features have contributed to particular areas of damage. In this case, areas corresponding to the side wall print, the manufacturer's logo and some of the cut-outs show particular cause for concern.

¹ XQi estimates board performance by using published data relating medium shear stiffness loss to BCT loss. Board performance is taken to be equivalent to the percentage loss in box strength if all the board making up an RSC were damaged to the same level.

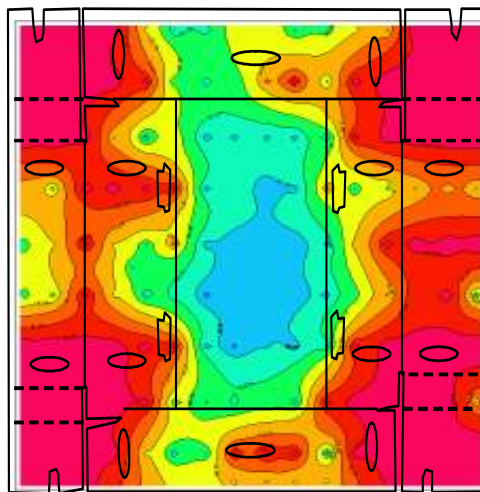


Figure 9 (a)

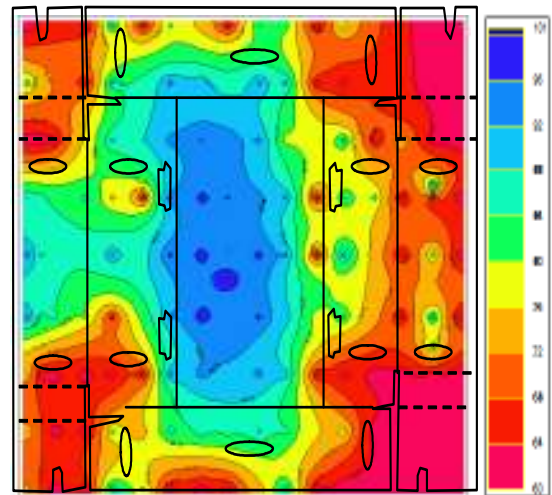


Figure 9(b)

Figure 9. Contour mappings of Mushroom box showing the board strength retention of (a) recent delivery (b) older delivery. Red colours are high retention loss areas.

Figure 8(a) and 8(b) shows the damage maps (BQM values) for the new and old deliveries respectively. The dark blue represents acceptable BQM values that will deliver the full potential performance of the box paper component strengths. Red and yellow colours represent high levels of damage.

Both boxes show high levels of damage, however the most recent box delivered (figure 8(a)) shows less high performance board making up the box and larger areas where the board is completely crushed and the medium no longer offers any significant shear stiffness at all. More disturbing is that the losses occur mostly in the doubled side-wall areas where increased strength is most needed to ensure adequate survival time in stacking.

Figure 9(a) and 9(b) show mappings of new and old delivery boxes representing the strength retained across the two boxes based on the BQM mappings of Figure 8. Again, the poor strength retention areas are represented by yellow, reds and hot pink. Both boxes show extended regions where damage has dropped the board strength retention to around 60% of the potential of this board. This loss of strength occurs predominantly in the load bearing tray walls.

Although the geometric design of the more recent tray is exactly the same as the older tray, one can readily see differences in overall level and position of high to medium damage areas. To show these differences more clearly the two mappings have been subtracted (old delivery – new delivery) to leave the difference in strength retention between the two blanks. This difference is mapped in the contour presented as Figure 10.

High values (ranging to blue) represent a decrease in performance from the old delivery to the new. Much of this retention loss is greater than 20%. The damage also appears to have been concentrated on the left hand side of the blank with the right hand side showing little change between the two deliveries.

It is clear that the variation in damage across the box is compounded by the variation apparent between deliveries. The most obvious issues arising from the analysis of figure 10 are the lower overall BQM values (differing on average around 6 BQM units in the unprinted areas and equivalent to a complete board grade) and the deterioration of the crease areas. Interestingly, the print areas appear to have accumulated less damage in the later box as shown by the negative differences shown in the block print area. This confirms the observation that print damage can be avoided if enough care and control is exercised during manufacture and conversion.

In summary, this box manufacturer has developed damage within a box from print and conversion settings and subsequently shown deterioration in that already uncertain performance with a subsequent delivery. Such variation is controllable at the time of manufacture with the appropriate technology.

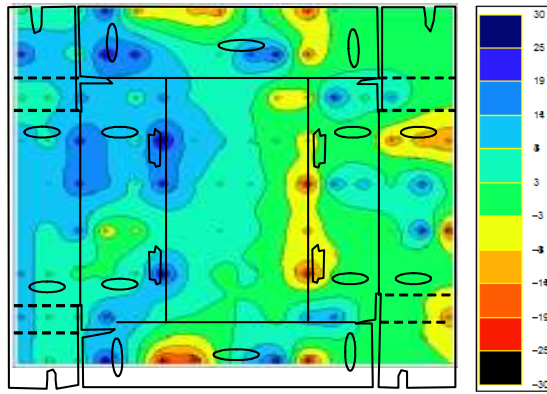


Figure 10. Difference mapping of board strength retention showing changes between new and old deliveries (old – new).

Case Study II - Publishing

Figure 11 shows the damage profile for an unused C-flute board blank aimed at packing books for export. This particular box was unprinted. The map shows two heavy sections of damage represented as two relatively well defined vertical stripes running the length of the main load bearing panel. These areas of damage appear to have been caused by transfer/feed rolls or belts that have applied a damaging level of pressure. These damaged areas would almost certainly compromise the performance of the box and as they are caused by process machinery settings that affect every box made in this order.

This example makes it clear that damage and its attendant loss of localised board performance can be due to factors other than the more usual print and print roller pressure. Care and re-setting of box conveyancing systems can also minimise damage and maximise board performance.

Conclusion

Existing box-to-box variability seriously affects the performance of commercially manufactured boxes. This variability comes about from a lack of understanding by the major box makers regarding the impact of poor process and conversion control in the box plant and the inability of manufacturer and user alike to measure relevant properties in a meaningful and convenient way.

New technology is now available for this type of measurement and can allow significant (10-30%) cost saving in box manufacture and large improvements in the consistency and absolute performance of boxes in field applications. The new measurement presented allows for finer spatial

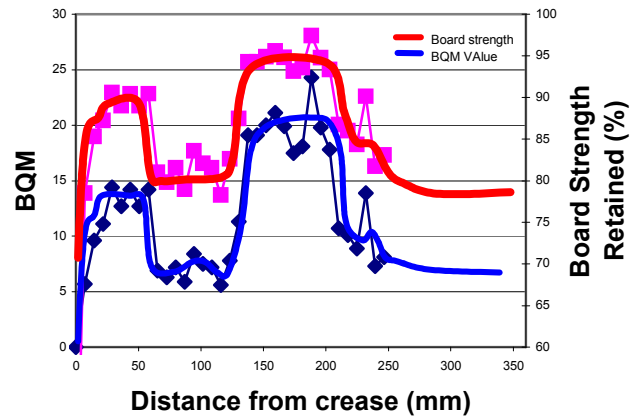


Figure 11. BQM and Retention profiles for a box designed to package books from major publisher.

resolution of the damage pattern and as a result a more definitive diagnosis of the likely causes of board damage and the resulting poorer box performance.

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