Using the BQM-1 to save money and lift quality.

Quality expectations

Experience with box makers has allowed XQi to estimate broad expectations of shear stiffness from different weight mediums. Large deviations from expectations most likely mean that there are unacceptable levels of process damage during manufacture. Figure 1 shows the BQM levels usually associated with acceptable quality corrugated board taken directly off the corrugator.

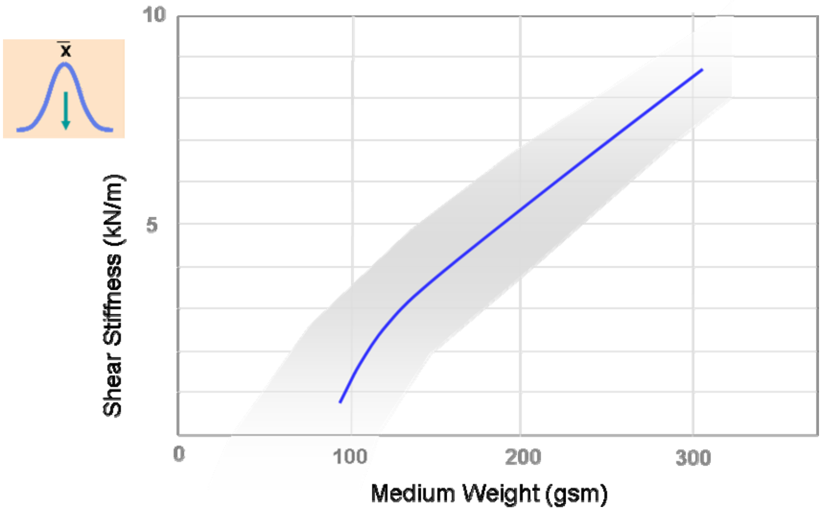


Figure 1. Industry performance of medium shear stiffness by medium weight.

Like most paper properties, shear stiffness of the medium is sensitive to moisture – changing around 5-6% for every 1% change in medium moisture. Typically, a modern corrugator should be controlling board moisture to within a few percent moisture and the maximum variation in shear stiffness due to moisture variation off the corrugator should be less than 10% of the BQM value. Greater moisture changes than this will not only affect the shear stiffness of the board but are symptomatic of major issues on the corrugator itself and are often accompanied by issues with warp and corrugator speed stability.

High combined board moistures will also cause greater damage at slitters and cutters and cause greater medium damage due to crushing on the corrugator itself.

Paper quality can also affect the md shear stiffness developed by the medium through the corrugating process. If the paper lacks stiffness in the md direction, is too thin (causing buckling during crushing) or too thick (causing delamination in the corrugator roll forming) shear stiffness will suffer. Often combined board measures such as ECT will not reflect the loss in performance due to the geometry and mechanism of the test. Many paper suppliers do not have a good knowledge of their own variation in paper strengths. A number of workers have shown that point to point strength variation at the scale of a typical box area can be as much as 30%. This will have a corresponding effect on the md shear stiffness capability of the paper and will affect the ultimate box strength, not only from the loss in paper strength but also its effect on the structural shear stiffness (the corrugated board panel's ability to resist bulging).

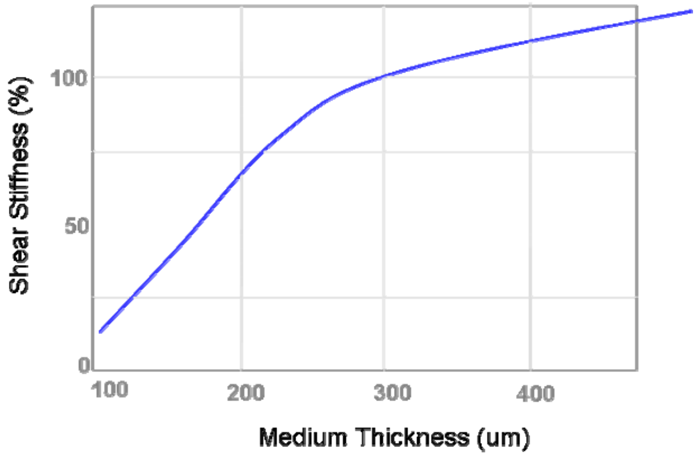


Figure 2. Modelled effect of medium paper thickness vs shear stiffness

In recent years, paper manufacturers have produced denser sheets with higher compression strengths (as measured by tests such as SCT). For heavier weight mediums, say above 150 gsm, these denser sheets provide general improvements in performance as they are stiffer and attract less damage in the corrugator train. However, lighter weight mediums tend to lose out in shear stiffness, with a corresponding loss in box compression value, because the medium is too thin to support the flute during crushing. As stiffness is sensitive to thickness, the overall result for these lighter weight grades is a loss in BCT. Figure 2 shows the modelled effect for papers with the same stiffness but different density (thickness).

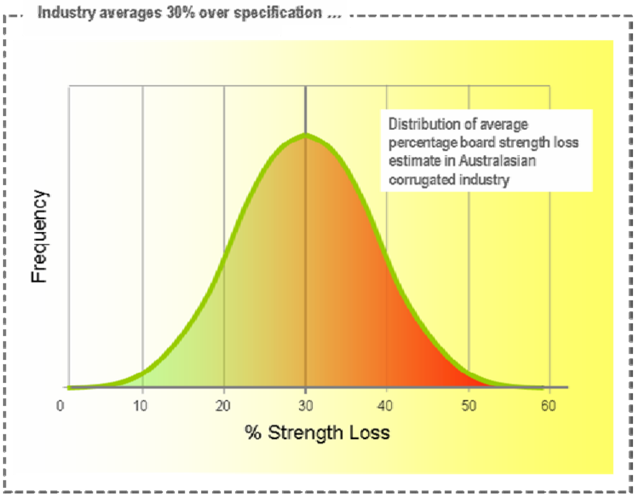
Box maker's should be aware of their supplier's paper strength variation and be careful with any attempt to lower the thickness of mediums < 150 gsm without first checking that the thickness effect does not defeat any paper strength improvement from the paper consolidation.

Market performance of run of mill corrugated boxes

Figure 3 shows the average performance of commercial box blanks with respect to BQM shear stiffness loss and retained BCT. For the large number of boxes tested the average loss in BQM value was greater than 50% and corresponding average loss in BCT was estimated to be 30%.

Measurements made in the US and Europe confirms these types of levels are typical in un-controlled corrugate plants.

Figure 3(a)
Distribution of strength loss estimate due to shear stiffness loss (medium damage) for unused commercial knock down boxes.



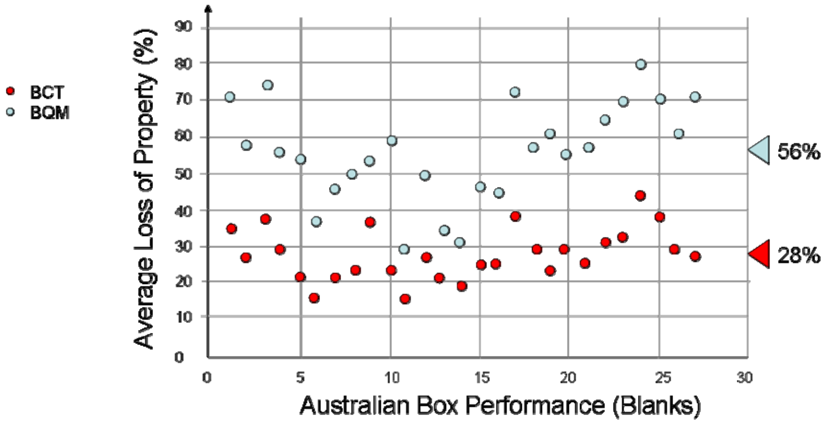


Figure 3(b) Australian box performance (various designs). Note the plot only presents *average* values representative of the entire blank (not worse case measured).

Identification of losses in the box manufacturing process

XQi have amassed enough experience within commercial box plants to estimate typical performance losses through the box manufacturing process. In un-controlled plants, the damage and Box performance loss can be estimated as in Figure 5.

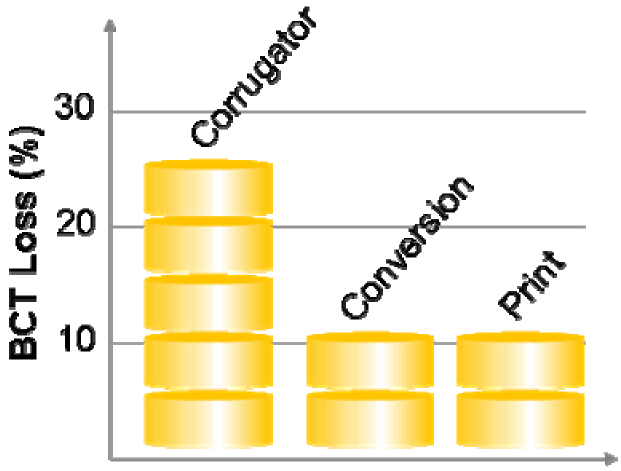


Figure 4. Typical break-up of performance loss for uncontrolled corrugator plant.

Interestingly, the greatest initial losses occur on the corrugator itself due to:

- Misaligned rolls and surfaces,
- Worn rolls,
- Inefficient or ineffective moisture or drying controls,
- Incorrect tooth shapes and
- Vibration resonances at particular corrugator speeds.

This is an important result, as lower than expected shear values from the corrugator will always lead to greater losses in subsequent conversion stages. Always start at the corrugator (at the paper quality if possible) to ensure that the following conversion processes (flexo folder gluers, print stations and die cutters) receive the board at the highest shear stiffness levels possible to give them the maximum chance of minimising board strength loss.

Decreasing the board moisture off the corrugator will appear to increase the BQM value but introduces other conversion issues such as cracking, warp and losses in the forming section of the corrugator, and so this short-cut to better quality should be avoided.

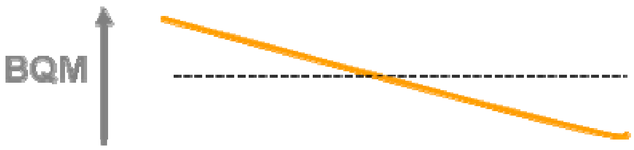
1. Practical Guide to measurement and implementation.

1.1 The Corrugator

A. Cross machine profiles can significantly down grade effective BCT performance. Measure BQM values at 100 mm intervals across the width of the board directly off the corrugator from the operator side to the drive side for each major flute type run on the corrugator.

Plot the results against distance from the operator side. The shape of the profile should be flat. A number of possible effects are typically seen on uncontrolled corrugators however:

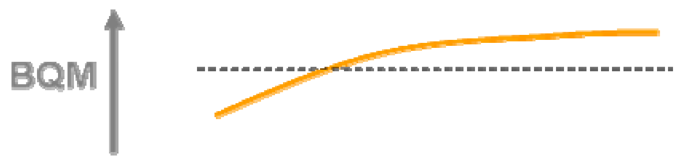
(i) Misaligned bearings, rollers, gaps or pressure rolls generally show a directional cd-profile.



(ii) Corrugator roll wear or incorrect crowning can show a number of profiles such as two shown below.

(iii) Moisture profiles across the corrugator showing that drying or wetting elements on the corrugator are not set correctly or are ineffective.

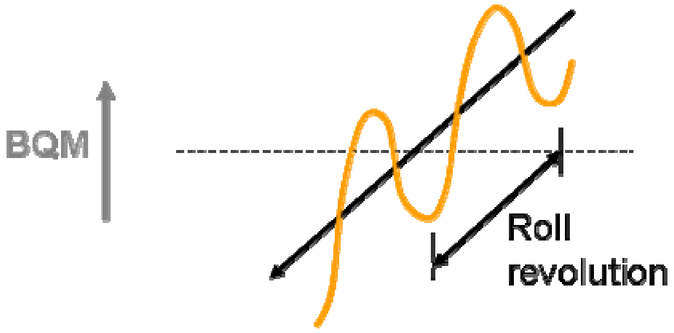
(iv) Depending upon the width of the corrugator, cd paper strength variation of the medium due to drying restraint on the source paper machine may impose significant variation across the width of the reel. From some paper-machines this can represent 15-20% variation in paper stiffness. It is very difficult to change these profiles if they are occurring on the paper machine and it is often best to find a supplier with less persistent variation in paper properties.



In uncontrolled corrugators variation in BQM values across the corrugator width can result in differences of 10-30% BCT. Such variation is particularly serious because it affects every job produced on the corrugator, and is equivalent to a 5-20% increase in board weight requirement to deliver equivalent sustained performance in the field.

B. Machine direction variation can generally be differentiated by the time or spatial scale of the variation. Typical variation comes from:

(i) Eccentricities in the bearings causing systematic variations once every revolution of the roller element – for example rider rolls, glue rolls or corrugator rolls. Incorrect cambers and variation in roll diameter may also cause periodic short term variation.



Take around 10 meters combined board directly off the corrugator for each flute type and draw a straight line parallel to the board edge in the manufacturing direction. Mark, in the manufacturing direction, sampling points at 50 mm (2 inch) pitch. Measure BQM values at each marked point and plot the measured values looking for periodic variation. If significant variation is found match the period of the variation to any rotating elements on the corrugator. For example, if a 1 meter period variation is found, a problem with a rotating element with diameter of 1m/π or ~320 mm will be the most likely culprit.

(ii) Short term variation that occurs over 10 minutes to 60 minutes can be associated with paper quality changes or process inadequacies such as inadequate heat capacity to cope with extended runs or adhesive metering

(iii) Long term variation or trends occurring over days can easily be identified by measuring board BQM values regularly off the corrugator. Often data from the BQM unit is automatically captured by the Ethernet interface available from XQi and directly entered into the plant's existing databases where reports showing trends and values can be generated routinely.

C. Benchmarking current vs best practice

Once specific corrugator performance in the MD and CD directions on the corrugator have been identified (and over time addressed), it will be necessary to benchmark existing performance by intensive measurement of shear stiffness values from the various grades coming off the end of the corrugator. The amount of testing required to obtain good measures of the performance and variation of each grade will depend upon the variation existing currently from a particular corrugator. Our experience is that this testing should be undertaken at the highest rate possible and over the full range of grades manufactured on the corrugator. A dedicated worker (perhaps a casual employed just for this activity) is ideal.

The aim of this work is to determine the average values achievable with the plant and the papers used in particular grades. Plant wide efforts should be aimed at increasing the average value for a particular grade and minimising the variation off corrugator.

A convenient way of pictorially representing your results is to map the measurements on the BCT potential – BQM mapping space as "***grade windows***".

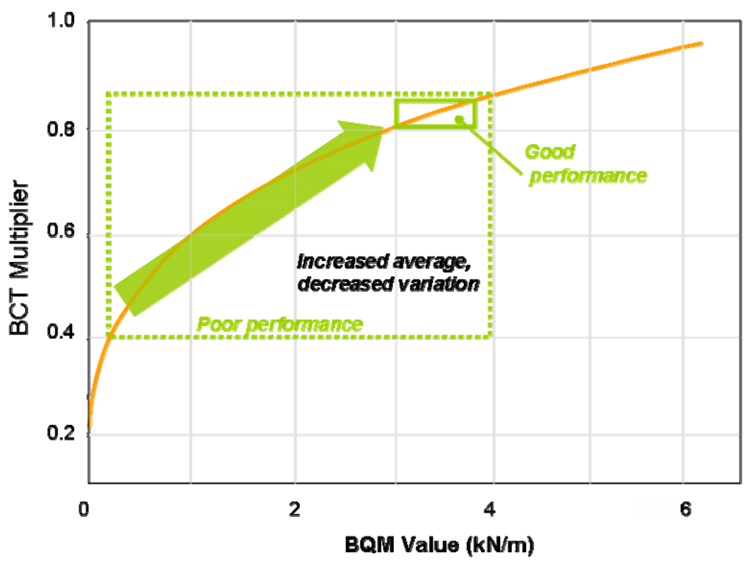


Figure 5. "Grade windows" are a convenient way of graphically representing changes in manufacturing quality performance.

Grade windows, represent the BQM variation and the corresponding estimate of BCT loss. Figure 5 shows the grade window for a 120 gsm semi-chem medium. The aim of any quality improvement effort using the BQM unit is to increase the vertical position of the grade-window, while minimising the area. That is, we would like the highest values for BQM while having the smallest variation in BQM. The figure shows the desired quality response as systems are improved going from the lower and larger rectangle (solid line) to the higher and smaller area (dotted line).

In this example the expected improvement in BCT can be read directly from the graph.

Figure 1 shows achievable values for BQM for various medium weights, and these values can be used as a guide to acceptable levels of performance. Naturally, the make-up and quality of the mediums will set the achievable values in a particular instance as will the equipment existing on the corrugator, but as an initial estimate the proposed values have been found useful in comparing benchmark data and judging the overall performance of the corrugator.

Once enough data has been taken for each grade over a representative length of time (say, a number of weeks), the average value for the grade and the variation can be calculated as the mean and the standard deviation. Best practice operation on the corrugator should deliver a co-efficient of variation off the corrugator of around 5%, for each grade.

An uncontrolled corrugator process (one that has not had BQM technology applied) will typically show 20-25% COV.

Setting specifications

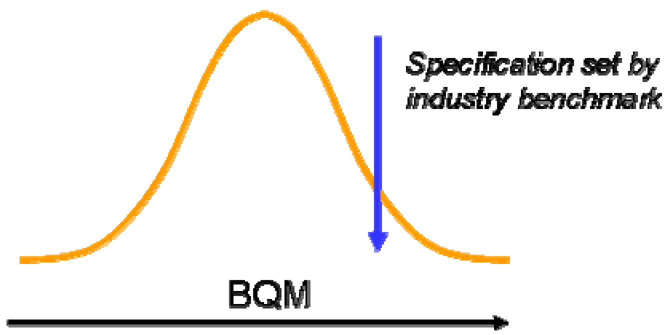
One of the advantages of BQM shear stiffness technology compared to other types of measurement (for example twist and torsional measurements), is that the BQM measurement is not affected by changes in liner weight. This means that acceptance specifications can be set for each medium grade. Unlike other measurements, specifications for each board grade (liner medium combination) is not required. For example, if a corrugator manufactures using 6 liner weights, 3 medium weights, and 3 flute types (A, B, C) corrugators using BQM technology would only require 3 x 3 = 9 specifications. The number of specifications to control board quality using twist or torsion measurements would be 3 x 3 x 6 = 54 to take into account the effect of the liner weight changes. Of course, if only C-flute was deemed important for stacking and base sag the number of specifications required would drop to only 3.

This benefit from XQi technology is important as it minimises the complexity of the quality system and allows the plant to concentrate on the damage to the medium alone, giving unambiguous indications of board quality from moment to moment. Our experience has been that lowering the number of specifications helps greatly in controlling and maintaining the corrugating process quality because, for example, a 112 gsm medium should always give the same number when in control no matter what liner or grade is being manufactured. It is very easy to judge whether damage is occurring to the medium in an ongoing way under these circumstances.

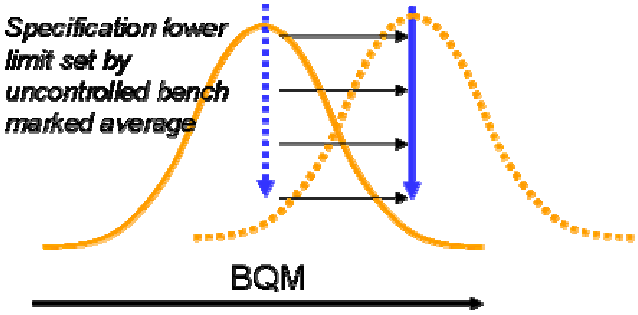
Having benchmarked the performance of the various mediums it is now time to set specifications that make sense to the plant.

There are a number of ways of setting specifications:

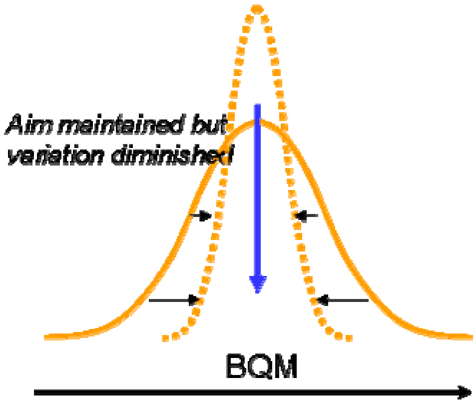
(i) Use the suggested values presented in Figure 1 for each medium weight.



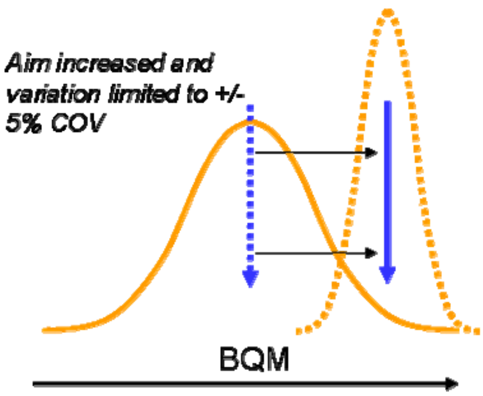
(ii) Set the average value measured from the corrugator as lower limit.



(iii) Set the average value measured from the corrugator as aim and set a low limit based on the standard deviation interval measured from the benchmarking work.



(iv) Nominate the highest achievable values obtained from the benchmarking work for a particular grade as the average aim and set limits of +/- 5% COV.



Which strategy to choose depends on the papers used, the capacity of the plant to limit damage during the process and the ability of workers to follow strict quality guidelines and adjust the corrugator on the run. In most cases, it is wise to start off slowly to avoid over-reaching during the initial stages of the quality effort. Experience suggests that there is more than enough "easy" targets in the uncontrolled manufacturing process to provide quick "wins" and maintain worker and management enthusiasm for the implementation of a BQM quality process.

Because of this, it is suggested that the first specifications should be aimed at lowering point-to-point and job-to-job variability. Choose an aim value for each grade that is achievable but stretching and lower limits that represent – say a 25% decrease in variation for the grade. At this early stage it is pointless to set a reject level as a large percentage of the board produced would probably be outside the reject limit for the grade. The aim BQM levels should be used as a guide to current job quality and to inform the production unit what equivalent performance losses are incurred from not maintaining correct levels.

For example, the following benchmark data distribution plot has been collected for a 110 gsm medium grade from an, up to this point, uncontrolled corrugator. The typical

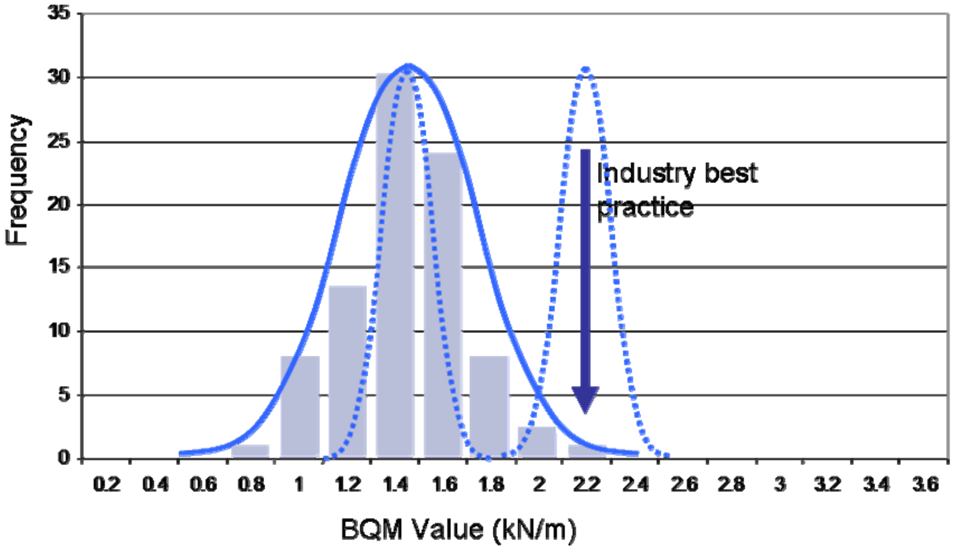


Figure 6 Typical benchmarking distribution plot of BQM for a ~ 110 gsm medium

normal distribution is apparent and suggests no particular skewing of the data due to one-off events or particular sampling bias. A number of important statistical and benchmark attributes have been included in the graph including the industry expectation, 5% COV limits, current mean and so on.

To underline the performance issues related to minimising crush off the corrugator it should be noted that in this case the difference in average value between the actual BQM values and industry best practice represents a BCT loss of around 12%. However, much board will be produced at lower levels due to the variation off the corrugator. At a BQM value of 1.0 – a value that 15% of the board coming off the corrugator is below – the loss in BCT is around 25%. Clearly, it is the variation in the process as well as the overall level of board quality produced that will be important to the customer.

In terms of correction strategies, the question to ask now is whether the business can tolerate product being produced that varies by 25% in BCT for nominally the same board grade. Note that subsequent conversion process in the plant – for example flexo folder gluers and rotary die cut stages may significantly increase the damage already identified at the corrugator.

Until the capacity of the equipment being used, corrugator rolls, profiles, gap settings, tooth shapes and double backer pressure roll settings and alignments have been properly investigated it seems reasonable to attack the high level of variability in the first instance, followed by a gradual increase in average BQM value as process elements are re-adjusted and brought into control.

In this case a reasonable ***initial*** strategy for the corrugator might be:

1. Do not reject board at any level.
2. Set the aim value to a moderately achievable level – say 1.8 from 1.5.
3. Work to bring the COV of the process (the variation) to 5%.

Meeting these requirements would mean an improvement in average BCT of ~5%, and lowering the variation to 5% COV would mean in increase in BCT experienced by the customer (15% production less than minimum) by nearly 10% - equivalent to a typical board grade increase.

Once the corrugator operation is in control and major influences on variability on the corrugator have been identified and understood (for example alignment of pressure rolls and gaps, alignment of corrugator rolls and corrugator wear levels, variation in adhesive, medium pre-conditioning (steam and/or waxing)), good practice will require reject limits (or at least a reject strategy) to be set to ensure that downstream processes do not wash away potential box strength further.

Typically, a corrective program based on BQM will also raise the average BQM level for a particular medium and allow the plant to judge the potential of the machinery employed to develop high integrity board.

Benchmarking conversion performance

Rotary Die Cutting (RDC)

To properly assess the impact of the rotary die cutter one must characterise the performance of the board into the die cutter and out of the die cutter to ensure that storage time and moisture changes do no inflate or deflate the effect across the conversion stage. Moreover, it is important to measure at points where there is print (particularly block print) both before conversion and after so that the print effect can be shown unambiguously.

Figure 7 shows an example of the type of measurement that must be made across the die cutter to show the effects of converting.

The aim of the converter operator is to maintain station efficiency, print quality and sharp cut outs but minimise the damage caused by incorrectly set pressures, misalignment or eccentricity of the form, incorrect rubber hardness and poorly formed creases that extend damage areas and seriously affect box stacking performance and base sag in produce trays.

Figure 7 shows the measurements that should be taken on the blanks into the RDC and those taken after conversion. It is important to match measurements made on the input and output side of the RDC. It is often helpful to obtain a printed and converted blank taken at the start of the run and mark-up an input blank to use as a template for measurement. In this way measurements can be closely related and the effect of the RDC process monitored.

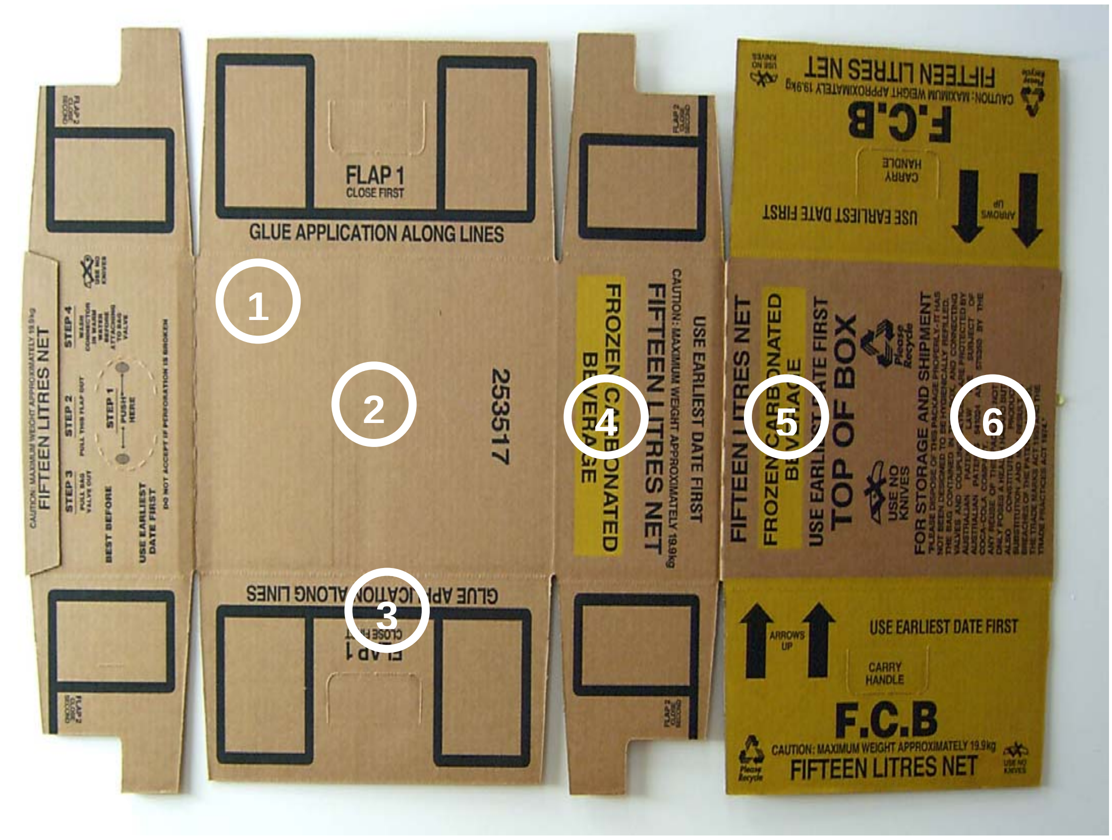


Figure 7. Example die cut box showing suitable sample measurements. Ensure that the same positions are measured on the way into the RDC to show conversion effects.

Measurement positions are chosen to give information regarding the effect of print and converter process damage. For the case in Figure 7:

- Measurement (1) represents unprinted areas but gives information regarding the quality of the creases.
- Mesurement (2) represents an unprinted (and hopefully undamaged) portion of the box and can be used as the reference to show the BQM levels that could have been achieved from the board.
- Measurement (3) reflects the quality of the crease and the impact of the hnd-hole cut-out.
- Measurement (4) and (5) represents the effect of the yellow block print on crushing and whether the crease damage has been extended.
- Measurement (6) shows the crushing due to the black print station.

Typically, the BQM loss through the Rotary Die Cutter should be no more than about 0.5 units – 1 unit at the most, and this will depend on the extent of print (block prints causing greater damage), the number of print colours/stages in the job and the weight and stiffness of the medium itself. Remember avoidable loss in BQM value can be equated to a loss in box strength and ultimately additional cost for the same performance.

Damage Mapping

Because of the high resolution of the BQM unit (about 1 cm^2) it is ideally suited to detailed examination of the damage around cut-outs, creases and to evaluate printed areas. Figure 8 shows a mapping undertaken on a bag-in-box application. In this instance the mapping was generated by measuring BQM values at 50 mm centres across the converted blank and estimating the equivalent BCT retention. To do this manually, even with the fast BQM technology will take many minutes. Nevertheless the information provided by a fully mapped converted RDC blank can give important insights about the die form being used and whether it has been correctly set up to minimise damage. Typically, die cut boxes are made from heavier grades and are expensive and yet they can lose up to half their board strength through poor control of the die cutting process.

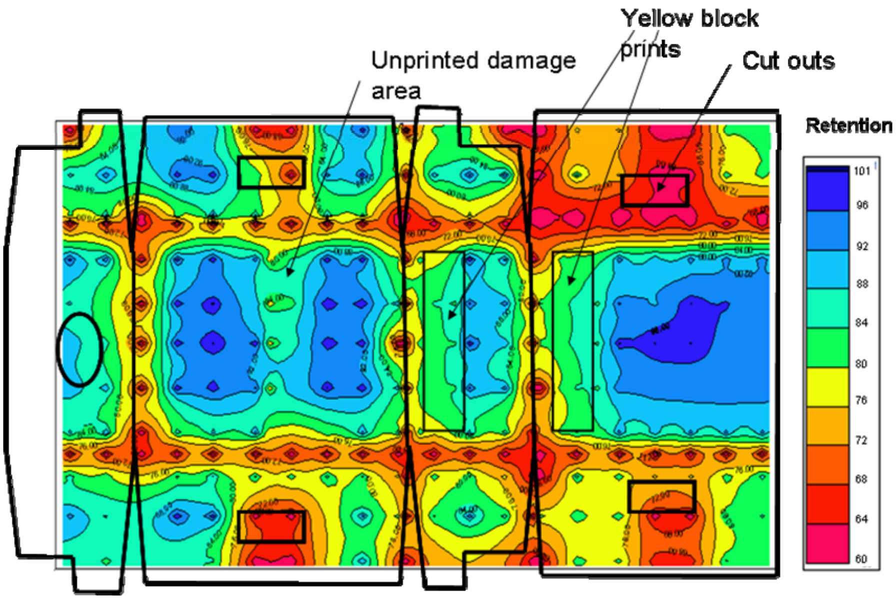


Figure 8. Box retention mapping generated from BQM measurements

XQi suggest that a full mapping be undertaken whenever a new die form is put into service. This will allow:

- The box and print design to be evaluated.
- The die operation to be checked
- The setting of rubber hardness and position to be checked
- The setting of crease and cut-out rules to be checked.
- Wear and damage to be assessed

In this way poorly set dies can be checked and re-made before large numbers of expensive boxes are manufactured and sent to customers.

To do this manually, even with the fast BQM technology, will take many minutes for each design.

XQi advise each corrugator plant to purchase a BQM table that allows the characterisation mapping of blanks to be undertaken automatically without supervision. Figure 9 shows a stripped back version of the table which is controlled from a personal computer via its serial or Ethernet port. When newly designed forms are employed the plant should take the converted blank and slide it into the table and allow the mapping to be generated. The BQM-1 unit fits into the table mounting. The table then maps the damage values measured against position on the blank and allows plant quality staff to assess the performance of the die form.

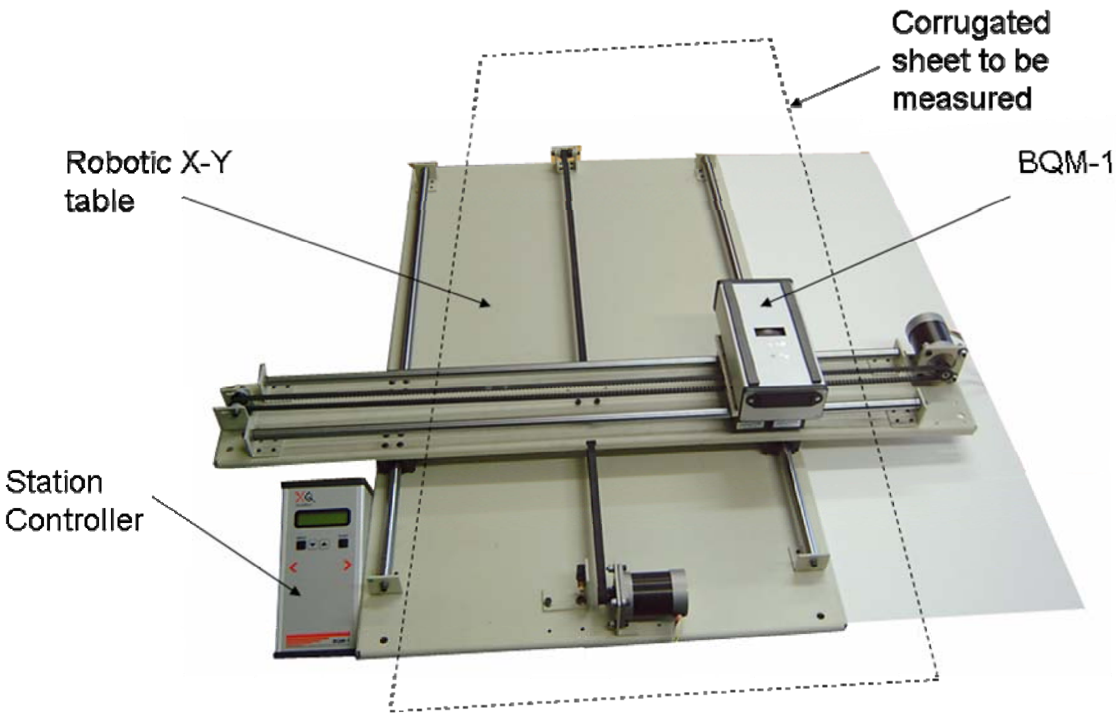


Figure 9 . X-Y robotic table automates the damage mapping of corrugated cartons and tests whether form quality and rotary die cut operation gives acceptable quality.

Creasing

It has been reported that poor or extended creasing can not only make auto-erection of boxes difficult at the customer's plant but also effect box strength by up to 40%. Creases should be crisp and the area of damage should only extend for a flute or two. Poor creasing leads to poor performance and problematic machine erection due to false creasing. Typically extended damage areas around creases are due to incorrect rubber or rule settings, or adjacent high print areas. Designers need to be aware that placing heavy block prints near creases will lower box performance substantially.

In uncontrolled box manufacture the majority of boxes have poorly defined creases that show extended areas of damage. Figure 10 shows the distance from a crease where 50% of the undamaged board BQM level has been recovered for various commercial box designs, grades and manufacturers.

The plot shows that more than half of the boxes tested (highlighted in red) have creases whose shear stiffness has not recovered 50% of the undamaged board value in +/- 15 mm (around +/- 2 C-flutes pitches).

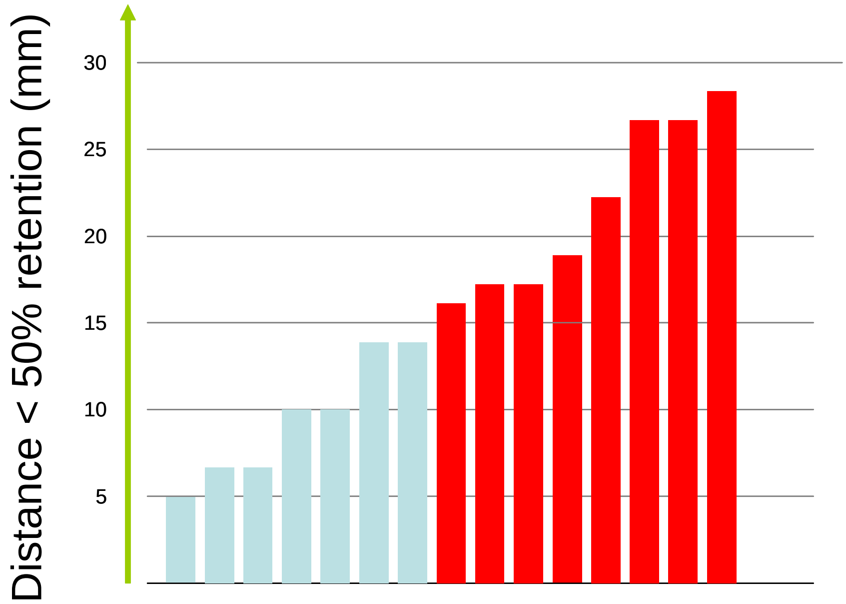


Figure 10. Crease performance of commercial boxes

Flexo-folder gluers

Flexo folder gluers provide similar issues to die cut board but tend to suffer from damage in the block and heavy print areas. Feed rollers that are not set correctly or are unevenly mounted can be a major cause of damage to corrugated board being converted.

A skilled flexo operator can set up standard steel/urethane feed rolls so that blanks will go through this nip with little or no crush. One procedure is to take an undamaged piece of corrugated board about 300 mm (6" wide) and use it as a feeler gauge. Open the nip, then close it to the point that the nip just barely grips the board. Lock in that nip setting for that run.

The feed rolls must not be worn or unparallel, and the board used as a feeler gauge must be representative of the whole job. If one of these ingredients is missing blanks may slip or feed crooked, resulting in jam-ups, out-of-square boxes, or registration problems. The usual response to jam-ups is to crank down on the nip and crush the board. Our experience is that 0.2 to 0.3 mm (0.008" to 0.012") feed roll crush is not uncommon.

Absence of nip rush at the beginning of flexo folder-gluer operation can be critical. It sets the stage for how much more crush damage will result.

Crushing can cost in other ways as well. For example, the RSC that was crushed in the feed nip so it wouldn't jam the flexo may not set up properly as it goes through he customer’s packaging line, causing a jam up there. This can happen if a crushed box panel has lost too much of its inherent stiffness, thereby breaking somewhere besides the scoreline when the automatic case-packer tries to open it up.

In-line variation sometimes occurs when then cylinders, feed rolls or forms are not properly seated or there is eccentricity in the die cutter itself. Figure gives an example where this has occurred. The comparison is made between the same job manufactured at different times. In this case the mapping is represented as a 3-D mapping to more easily show the variation from left to right.

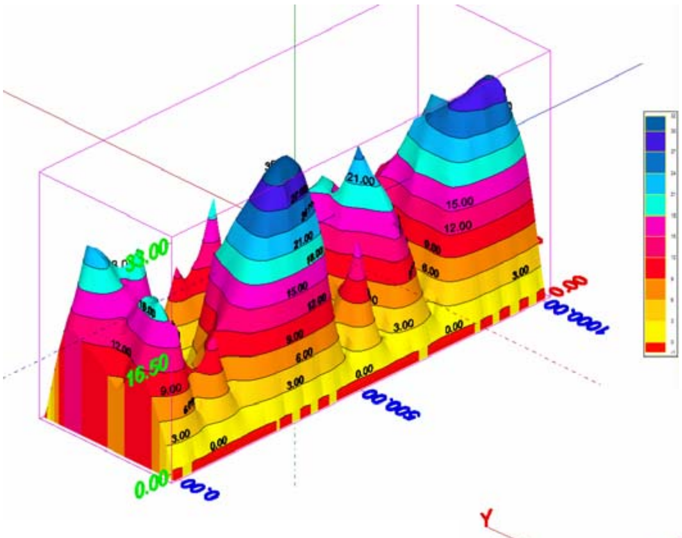


Figure 11(a)

Figure 11. A 3- damage mapping of the same box made on different conversion lines. Fig 11(a) shows the general level in undamaged areas is maintained down the length of the box Fig11(b) shows systematic damage caused by misalignment.

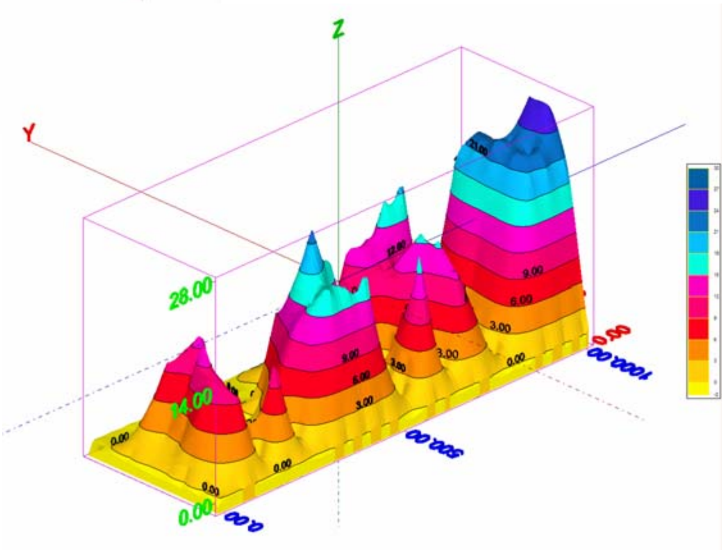


Figure 11 (b)

To check for this sort of damage take approximately 5 measurements down the length of the converted blank in areas that are away from cut-outs and creases and in unprinted areas. Any significant trends should be clear.

Appendix 1

Relationship between BQM shear stiffness and box quality.

Most box makers utilise design systems based on a variation of the McKee equation. One version of this is shown as:

$$BCT = kECT^{0.75}(D_x D_y)^{0.25} Z^{0.5}$$

Where the ECT part of the equation reflects the quality of the papers, and the flexural rigidity part of the equation represents the structural stiffness or rigidity that will be expected from the box panel. In sandwich structures, like corrugated board, part of the structural rigidity depends on the shear stiffness of the core material or structure. The md or lateral shear stiffness can be thought of as indicating the ability of the corrugated board to resist machine direction sliding of the two liners with respect to each other (see Figure 1). This property is important in managing bulging in loaded corrugated boxes and poor shear performance can often be caused by loss of integrity of the combined board medium due to crushing and damage during manufacture.

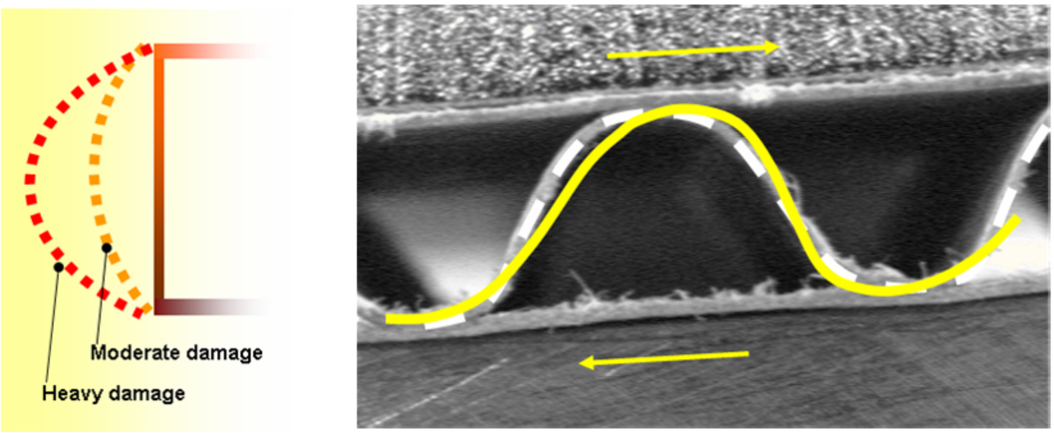


Figure 1.

The shear stiffness is affected not only by the slenderness of the medium compared to the flute height, but also the level of damage sustained during manufacture and conversion. Commonly, this damage is due to crushing from misaligned elements in the corrugating and conversion processes.

Because of spring back of the corrugated board, thickness measurement or caliper is not a good measure of the crushing experienced by the board and it is known that 10-15% of the box strength can be lost before one can confidently show a thickness loss in the combined board.

The BQM-1 unit measures the shear stiffness using a resonance method that is more fully explained elsewhere. Suffice it to say that due to the excellent predictive power of the McKee equation it is possible to predict the effect of shear stiffness loss on the typical box strength. These estimates have been shown to relate well to practical measurements made on commercial boxes. Figure 2 shows the generic relationship between md shear stiffness and the fraction of box potential strength retained as the shear stiffness of the medium changes. As expected from the McKee equation (1), the relationship is non-linear and has a greater effect the lower the shear stiffness value is away from the full box potential provided by the papers used in the corrugated board.

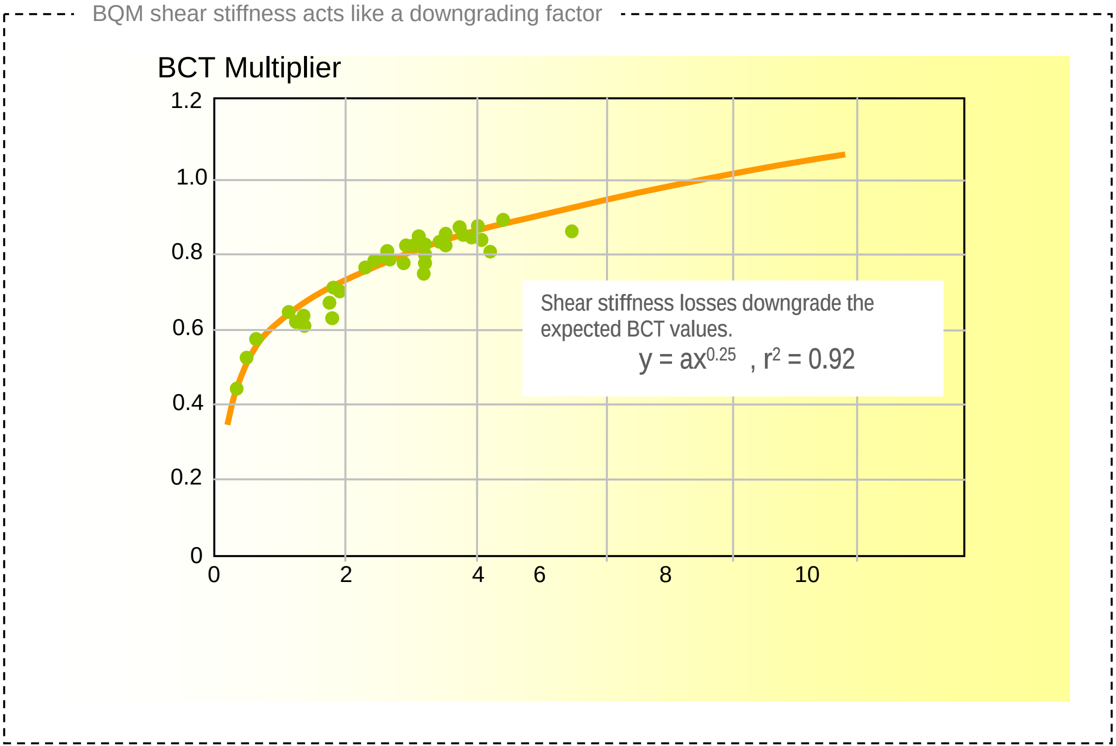


Figure 2.