

Determining the Root Causes of Boxes Stacking Strength Failure and Find Possible Solutions

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Abstract

There are various challenges that manufacturers of corrugated packaging boxes encounter in dealing with waste and customer complaints, and one of them which has been on the increase at XYZ Boxing is the collapsing of boxes in the market. Such complaints result in customer dissatisfaction, and they tend to seek products from other suppliers/competition. The purpose of this study is to find root causes of the recent increase collapsing issues as raised by the customers by evaluating raw materials mechanical performance over the past few years, verify if folding settings affect the box compression strength and compare how design choice (straight crease vs off-set crease) affect box compression strength. Supplier 1 for mechanical components was found to be generally performing better as compared to Supplier 2, but both suppliers were found to be poor. Changing folding settings does not bring about significance change in box compression strength and McKee formular underestimate box compression strength when using Edge Crush Test results to predict the strength of certain box; and that straight crease design delivers better box compression strength results than offset crease design. The proposals from the finding include evaluating all board grades mechanical performance and source the materials as per better performing supplier, including working with the suppliers to find the root cause of raw materials mechanical properties decline.

Keywords

Corrugated Packaging Boxes, Box Compression Strength, McKee Formular, and Edge Crush Test

Introduction

Corrugated packaging boxes play a vital role in storing and distributing of goods by ensuring that the load they carry is protected and contained until it reaches its final destination, be it at retailers or at consumers. Once boxes fail at the storage and or during the distribution, damage is likely to occur on the contents they carry or the whole load become unstable. The corrugated industry produced over 184 million tons worldwide in 2021, with the projection of over 191 million tons for the current year, as depicted in Figure 1 below.

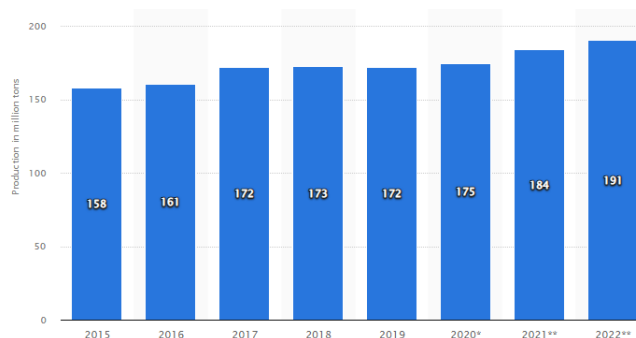


Figure 1. Corrugated packaging boxes produced from 2015 to 2021, and projection for 2022 (Tiseo, 2022)

Since the beginning of the 2022, the company has been experiencing high figures of waste through its processes that goes over the target of 1.5%, see Table 1 below which shows waste figures.

Table 1. Waste figures for the year 2022 (Boxlee 2022)

Month	Waste %
Jan-22	2.25
Feb-22	2.37
Mar-22	1.67
Apr-22	1.00
May-22	1.57
Jul-22	2.07

One of the main reason the company is experiencing such a lot of waste is collapsing of the boxes in the market. Since the beginning of the year 2022, there has been a lot of complaints regarding the performance of the boxes in the market or at the customer. Collapsing complaints are regarded as unusual as the organization did not previously receive such complaints in the magnitude, they are being received this year. As mentioned earlier, collapsing issue was not raised last year, but this year the issues has already contributed 5% of the total waste recorded.

The most concerns regarding the collapsing of the boxes are as follows:

- Customer products are also affected, for instance if boxes collapsing are carrying food such as fruits, such product will be crushed, and customer will not be able to salvage most of their products that on packed in the collapsing boxes
- Other products that may be packed in the collapsing boxes such as plastics may lose shape which may affect their usability and render them waste.
- Such complaint becomes expensive since
 - Products are mostly produced by batches in quantities as per customer ordered, so if the complaint arise it is expected that whole batch is affected, that means nothing can be salvaged on that specific batch and the entire batch becomes waste (100% waste on that batch against company's target of 1.8% per batch)
 - Customer affected when they claim they also include their products affected as mentioned above
 - Most importantly, when customers start experiencing such issues, it damages the reputation of the company, and they are likely to switch over to the competition if they see that such issues are not being speedily resolved.

Towards the end of 2022, XYZ Boxing has been experiencing a lot more of boxes failures/collapsing in the marker than previously reported; and as shown below on figure below, collapsing complaints have risen by 400% and 233% in when year 2022 is compared with year 2020 and year 2021, respectively. The collapsing of boxes issue is costing the company highly due to :

- the fact that customers are likely to returns such batches that are failing and
- Some customers may also claim the loss from due to their products damage because of collapsing boxes. Most critically is that when customers start experiencing boxes collapsing issues, the reputation of the company is damaged, and customers are likely to switch over to the competition if they see that such issues are not being speedily resolved.

1.1. Objectives

The aims of this research are to investigate if:

The level of raw materials handling performance

Raw materials performance handling is maintained the same level between two suppliers

Changes in machine folder settings can increase box stacking strength while ensuring that there is no notable change in folding variables process capability

Changes to design does negatively impact the performance of the box.

2. Literature Review

Manufacturing waste impacts both the environment and the economy, as materials waste add to financial loss of the company and affects ecosystem negatively (Daoud et al.2018). The greatest route a company can take to minimize waste is to avoid making producing it, as producing a new product needs utilization in energy and raw materials which must be acquired from the earth, as a result reducing and recycle becomes the most valuable initiative (April 2016). Studies have shown that successful organizations employ Lean Manufacturing to minimize waste, where following such practice will not only help the organization to find root causes of the waste issues but will also help eliminate such issues permanent, which will also address one of the weaknesses of the company understudy is experiencing (Sable & Dakhore 2014). Lean manufacturing can best be described as removing waste in a production process or anything that does not add value to the end product is waste, and also stated that lean thinking can be summarized in five principles: precisely specify value by specific product, identify the value stream for each product, make value flow without interruptions, let the customer pull value from the producer, and pursue perfection (S. Rogstad 2010). The practice follows these steps in dealing with waste,

- identify the problem,
- taking observations of the problem,
- find the root cause of the problem/s,
- find solution for the root cause,
- implement the solution, and
- observe and sign off (Sable & Dakhore 2014).

2.1 Strength of the corrugated boxes

Corrugated boxes must meet Box Compression Strength/Test (BCT) value standards to support the use of the box and the most vital requirements of the corrugated box as packaging are containability and stacking strength and is the largely utilized to test the stacking strength of the corrugated boxes and generally show a curve of compressive Force versus Deformation (Aji et al. 2020). BCT is defined as the quantification of the highest compressive force per unit width that a corrugated box can resist during a compression test up until it reaches the collapsing phase and it the most test of the corrugated box and it helps in assessing the strength limitations as well as the overall strength of the box (Maheshwari & Shenoy, 2017). BCT of box usually include the deflection (as shown in Figure 2 below) at collapsing or at the end of a specific load application, which is the difference between the box heights at the beginning of the test to that at the end and it is a measure of how much a box is compressed at the end of a test (J. Singh et al. 2007).

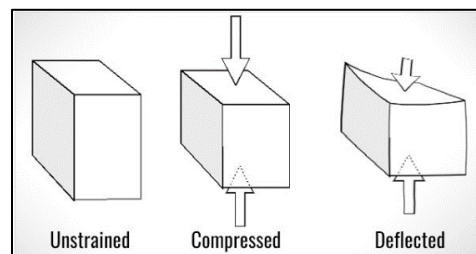


Figure 2. Deflection of compressed corrugated box (J. Singh et al., 2007)

The actual BCT of corrugated will decrease overtime due to various environmental factors such as stacking height, mass of the filled box, the number of layers packed high, types of pallets used and overhang, unitizing practice, and number of pallets high packed at the storage, storage and distribution time, and transportation circumstances (Clayton & Bouldin 2018). To assess the influence environmental conditions, an “environmental factor” should be established (Clayton & Bouldin 2018). The factor is a number obtained from the correlation between BCT at environmental circumstances, as it is associated to the packed pallet from distribution and storing practices the container will be subjected to in its predictable transportation settings (Clayton & Bouldin 2018).

The major strength of a container is mostly derived from the corners (Zhang, Y. Chen, J. Wu, Y. and Sun 2011), as demonstrated in Figure 3 below. Practice such as overhang must be avoided as it has been found that the deficit in BCT of packed boxes as an effect of overhang can range between 23–49% but varying on the extent and direction (length, width or adjacent panel) of overhang (J. A. Y. Singh & Saha 2011). Another practice that must be avoided is misalignment of the boxes when packed on each other on a pallet as it plays a significantly role in decreasing the strength and the lifetime of the box, where the percentage decrease in BCT value can be as much as 11% and 31% for 90% contact area and 80% contact area, respectively. To ease the consequences of environmental factors, the end user must minimize the habit of particular methods that negatively affects the strength characteristics of the corners, including overhang on the pallet, packing on pallets with only a few slats, excessive shrink warp tension, and using “interlocking” stacking patterns (Meng et al. 2007).

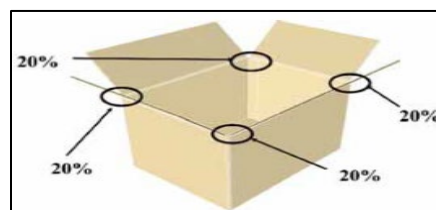


Figure 3. Corrugated box showing distribution of load/ weight (Maheshwari & Shenoy, 2017)

It has been found that column stacking practice results in higher strength as compared to interlocking stacking pattern, and while stacking boxes, one need to ensure that the four carton corners are placed in alignment (Zhang, Y. Chen, J. Wu, Y. and Sun, 2011), see Figure 4 below.

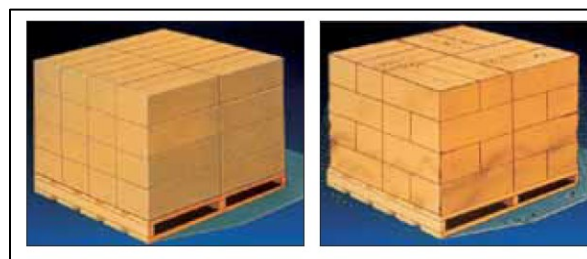


Figure 4. Column and interlocking stacking pattern of corrugated boxes (Meng et al., 2007)

The mechanical properties are important design feature because the function and performance of a product depend on its capacity to resist deformation under the stresses encountered in use, hence in design, the usual objective is for the product and its components to withstand these stresses without significant change in geometry (Ulrich & Eppinger, 2016). Edge Crush Tests (ECT) and Flat Crush Tests (FCT) are the main two tests that determine if the mechanical properties of corrugated board will meet set or targeted performance of the box in the market (Chalmers 2019).

2.2. Mechanical Property determined by ECT

Projecting of raw material performance plays vital role for designing and manufacturing of products made from corrugated box, and the ECT testing practice was established to give a way to determine the strength of a corrugated box as it associated to BCT (Garbowski et al. 2021). The development of ECT testing has progressed through six main methodologies: Ring crush, Concora liner edge crush, Concora fluted edge crush, Swedish short span test, Necked Down edge crush, and what is now simply referred to as the Edge Crush Test, as shown in Figure 5 below (Baker 2016).

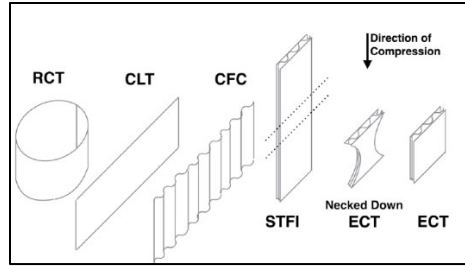


Figure 5. ECT test specimens in order of development from left to right (Baker 2016)

ECT is the single most important mechanical property in predicting BCT and the test helps to authenticate the quality of the raw materials is used as a primary quality control parameter since it correlates to box stacking strength (Gaikwad et al., 2016) (Kahn et al., 2010). Edgewise strength has proven to be the crucial measure to predict BCT even though in South Africa, there is an inclusion of FCT on the corrugated board tests standard (Ahmed & Bhoomkar 2013). The differences in BCT varies with perimeter of the box, including the ECT, and in general, the higher the ECT of the board, the higher the BCT (Dimitrov, 2010). The test is carried out on specimens of 25 mm × 100 mm that are usually thicker than 1 mm (Garbowski et al., 2021). In the ECT, force is applied to one side of the box, perpendicular to the ridges (as shown below on Figure 6), until the board gets crushed and gives an accurate idea of a box's strength when they are stacked and shipped by pallets (Clayton & Bouldin 2018).

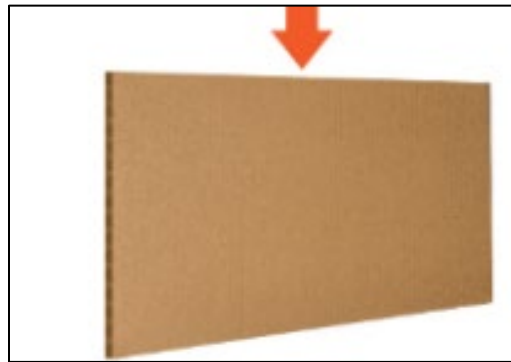


Figure 6. Edge crush testing of a corrugated board (Agrawal & Shetty, n.d.)

Particularly to BCT of the box, a theoretical formula has been developed (Dominic et al., 2014). This formula sums up the compressive strength of linerboard and medium to estimate the compressive strength of corrugated board and reads(Dominic et al., 2014):

$$ECT = k(\sigma_{L1} + \sigma_{L2} + a\sigma_{Fl})$$

σ_{L1} = compressive strength of outer liner
 σ_{L2} = compressive strength of inner liner
 $a\sigma_{Fl}$ = compressive strength of medium or flute

k = is a dimensionless variable related to testing errors, testing method and manufacturing variables at the corrugated plant.

The above formula provides good predictive precision to examine the mechanical property of corrugated board with respect to its constituents, and is widely used in industry to relate the corrugated board properties to the paperboard properties (Chalmers, 2019). Results from the test, the combined board ECT values, nominally indicate a fundamental material property of corrugated board, a value important because it is associated to the expected BCT and thus the performance of the finished box (Chalmers, 2019), and the relationship is further discussed below in the next section 2.3.

2.3. Relationship between ECT and BCT

The BCT of a packaging container of the RSC design can be anticipated from ECT value of the board (Manoj 2015). The ECT & BCT, Stiffness & BCT and Thickness & BCT links were proven to be solid and positive (Manoj 2015). This relationships can be expressed through McKee formula when one needs to predict the BCT through ECT value (Shenoy et al. 2016). For this reason, heavy emphasis has been put on ECT testing as a means of predicting overall box performance (Baker 2016). Even though the McKee formula is a generally accepted design formula, it is still up to the packaging engineer to evaluate the degree to which this formula might apply and perform the physical tests to assure safety (de la Fuente et al. 2018). McKee formula must only be utilized when the length to width ratio or the height to length ratio of the box is not too large (Mrówczyński et al. 2021). BCT can be predicted using the McKee formula below (Kahn et al. 2010):

$$BCT = 5.87 \times P \times \sqrt{hZ}$$

Where:

P = ECT value

h = thickness of the corrugated board

Z = box perimeter 2(L + W)

The effect of box height (which is not included in McKee formula) is that the box become weaker as the height increases due to the wall buckling, where the compression strength dropped by as much as 62% from the 127mm to 1219mm box heights, which points out the weakness of using McKee formula (Aloumi et al. 2015).

2.4. Mechanical Property as determined by FCT

During manufacture of the boxes, the printing, cutting and folding processes known to substantially cause damage to the box due to the severe mechanical deformations encountered, where corrugated board can be damaged by flat crushing loads when going through rollers or belts during the box making process, and the flat crush test is generally regarded as indicating the extent of this damage (Selebalo 2019). The FCT is defined as measure of the resistance of the flutes in corrugated board to a crushing force applied perpendicular to the surface of the board and can only be applied to single wall board, (Ahmed & Bhoomkar 2013). The test allows to know the load a corrugated can handle when the a specimen is placed between to plates and crushed (see Figure 7 below), where the red arrows indicate the direction of movement of the rigid plate which crushes the board (Gudavičius 2018).

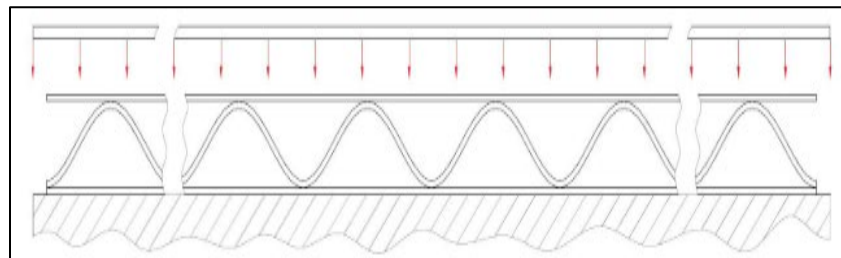


Figure 7. FCT sketch (Gudavičius 2018)

The primary interest of the test is to determine if the medium's contribution to combined board rigidity has been compromised. A high flat crush results indicate the good board grade combination between the flute and liners, where a low flat crush can indicate a number of conditions including low medium strength, leaning flutes, and/or crushed flutes (Tappi 2006).

2.5 Folding process on the corrugated boxes

The general guideline when producing the corrugated boxes is that they must be pre-created in order to prepare for the next step on the process creasing (The Corrugated & Converting Specialist, n.d.), as shown below in Figure 8. The pre-creasing involves crushing of the corrugated box in order to get proper folding of the box at the end of the line (Correira, n.d.). Care should be exercised when closing the nip on the pre-creaser as excessive impression will affect the folding of the box. More impression at the pre-creasing stage compromises crease definition observation (Correira, n.d.).

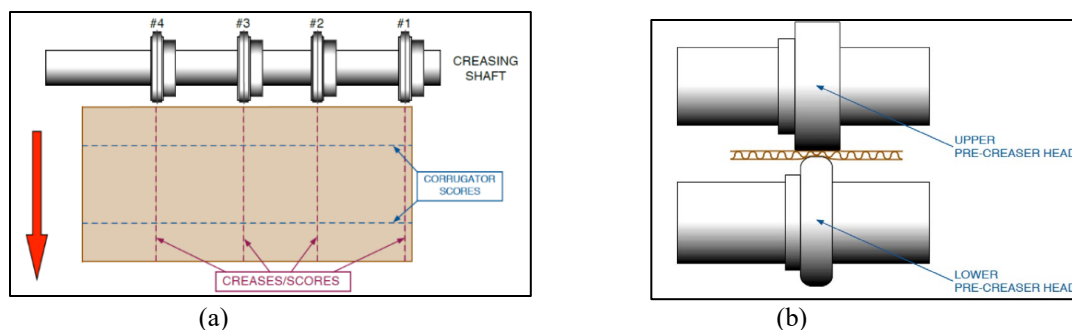


Figure 8.

Pre-creasing (a) and creasing (b) of the corrugated box at the slotting section (Correira, n.d.)

After pre-creasing, the board goes through creasing as shown in Figure 8 (b) above, and the sheet of board is scored/creased as it passes between the creasing heads of the scoring/creasing unit, and creases are where the box will fold, where the score/crease indentation formed in the sheet of board determines the position of the fold (Correira, n.d.). By its nature, the thicker the corrugated board, the more crushed it will be on the corners, and that may also translate to weak corners that are prone to damage and/or poor folding. The folds created by the scoring/creasing heads determine the finished carton dimensions as shown below on Figure 9. As a guideline in order to get the proper folded box (The Corrugated & Converting Specialist, n.d.),

- The pre-crease impression should be set to board caliper x 0.5 (1/2 board caliper)
- the crease impression should be set to board caliper x 0.25 (1/4 of Board caliper)

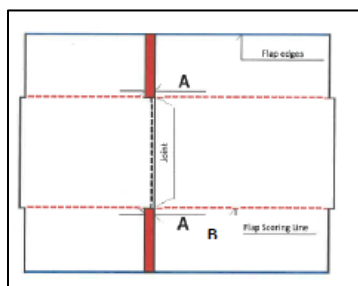


Figure 9. Sketch of completed flat corrugated box (The Corrugated & Converting Specialist, n.d.)

As explained in section 2.1 above, 80% of corrugated box strength is derived from corners. If box corners are excessively crushed during the process/conversion, it is expected that its stacking strength will be compromised. At times during the manufacturing of the boxes, one of the troubleshooting solutions when certain BCT value is not reached is to change folding settings (to crush less) on the corners in order to enhance or increase the BCT value. No study has been done before to verify if such assumption has a direct impact (increase) BCT, hence it was necessary to also include on this research as experimental study. The research will focus on experimental study in setting pre-creases and creases and review the following:

- how different settings affect BCT by comparing means/averages of different settings, and
- verify how experimental settings to enhance or increase the BCT affects folding process capability (SPC) by comparing process capabilities of different settings (current vs experimental). SPC and experimental studies are further explained below in sections 2.6 and 2.7.

2.6. Statistical Process Control SPC

Statistical Process Control (SPC) is a procedure for open or closed loop control of manufacturing processes based on statistical methods in monitoring the process behavior, and is a standard method for visualizing and controlling processes on the basis of measurements of randomly selected samples (Madanhire & Mbohwa 2016). All processes have natural variation (normal variation) and the purpose of SPC is to control this by means of samples and to separate special causes of the variation from the natural variation (Soriano et al. 2017). There are five key points of the

rationale behind SPC (Madanhire & Mbohwa 2016), namely: control of variation, continual improvement, predictability of processes, elimination of defects/waste, and product inspection.

Since in many organization the responsibility for quality in any manufacturing process lies with the owner of the process (operator), management must provide the tools to know whether the process is capable of meeting requirements and also whether the process is in fact meeting the requirements (Sorianoa et al. 2017).

Basic run charts, which are running plot of a certain measure quality characteristic are widely used due to their simplicity in monitoring the process (Bagchi 2020). Average (\bar{X}) charts and range (R) charts are part of the SPC systems strategy. It is a type of a signal whose operation is based on evidence from the small sample taken at random during a process (Howard, 2003). The output of any process can basically be described in terms of two parameters, namely the process average and the process standard deviation (Howard 2003). The control chart is the central object of the SPC and an important tool of quality management and determining process capability, which is the range over which the natural variation of the process occurs as determined by the system of common causes and assessing the relationship between the natural variation of the process and the design specification (Appollis 2019) (Moser 2018). To determine whether the process is conforming to specification limits the process capability must be determined by a procedure, where the position of a specific process is expressed relatively to the required specifications (Sunadi et al. 2020). The process capability index (Cpk) is interpreted as follows (Wooluru et al. 2014):

- Cpk < 1, process does not comply with specifications.
- Cpk > 1, process complies with specifications.

As mentioned previously, Cpk values of folding variables were compared on experimental study (see section 2.7 below) when different folding settings (pre-creases and creases) are compared in determining if changes in settings brings about higher BCT value.

2.7. Experimental study

Experimental research is a study that strictly adheres to a scientific research design, it includes a hypothesis, a variable that can be manipulated by the researcher, and variables that can be measured, calculated and compared, and most importantly, experimental research is completed in a controlled environment (Welman et al., 2007); where in this study folding settings (independent variables) on pre-crease and creases were variables manipulated and BCT and folding Cpk values (dependent variables) were variables measured. The purpose of experimental research seeks to determine a relationship between two variables, the dependent variable and the independent variable (Cash et al., 2016). After completing an experimental research study, a correlation between a specific aspect of an entity and the variable being studied is either supported or rejected (Welman et al. 2007).

The basic types of experimental study describes the types of experimental approach, how each type controls extraneous variables, and what type of evidence each is capable of generating (Cash et al. 2016). **Randomized or true experiment** is the type used in this study, where machine folding settings on pre-creasers and creasers (independent variables) are changed and reviewed to experiment the following (dependent variables) (Cash et al. 2016):

- how different settings affect BCT by comparing means/averages of different current settings and experimental settings, and
- verify how experimental settings to accommodate or increase the BCT affects folding process capability (SPC) by comparing process capabilities of different settings (current vs experimental)

2.8. Straight creases vs off center creases designs

Another area that should be looked at during design is the inclusion of offset creases on the flaps, as experimental study results indicated a substantial decrease in the BCT of packaging in the box of the offset creases (Mrówczyński et al., 2021). The decrease in BCT results from a certain sequence of loading, in which the edges of the two shifted (elongated) walls of the package are loaded first, while the other two are only loaded after buckling and/or crushing of the first two, see Figure 9 below (Mrówczyński et al. 2021).

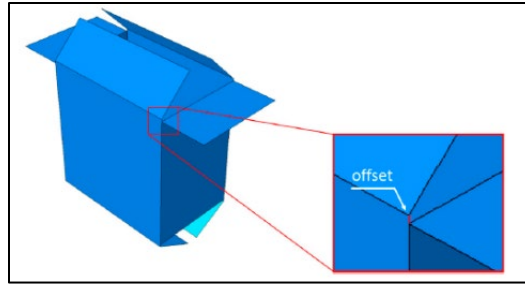


Figure 9. Box with offset flaps (Mrówczyński et al., 2021)

The compressive strength of a corrugated box during its life cycle is significantly impacted by the conditions that it encounters through a supply chain, and given the variation of impact to the integrity of the boxes throughout the course of the supply chain, only 25% to 30% of the measured preserve its strength from packing, storage and during transportation until its final destination (Dominic et al. 2014).

2. Methods

2.1. Instruments for data collection and validation of data collection methods

For ECT and FCT, crush tested machine was used to test mechanical properties of raw materials, and box compression tester was used to measure stacking strength (BCT) of the boxes. Measuring tape was used to obtain box folding gaps and fishtailing variables. To validate data collection methods on mechanical properties and stacking strength, ECT and BCT of the same batches on board and boxes respectively, were tested at XYZ Boxing and at the sister company, and differences in results were found to be insignificant, which validate the methods used. MSA was completed on measuring folding gaps in order and methods was found to be valid.

2.2. Methods of data collection and data analysis

Quantitative data was collected, which is much sorted for statistical and mathematical analysis, and made it possible to illustrate it in the form of charts and graphs for all four research objectives. Also, continuous data values, which falling on a continuum possessing the possibility to have fractions or decimals have been used. The data collected for the study were analyzed by comparing statistically weighted means in answering the research questions, and histograms and trendlines were used to graphically present the data.

3. Data Analysis

As mentioned on above section, methods used to analyze data were statistically weighted means, and below sections shown data analysis of each research questions.

4.1. Raw materials performance assessment over the past five years

Research objective 1 dealt with checking if the materials performance on ECT and FCT variables have been gradually decreasing for the past years for both suppliers, Corruusual and Everest, for the top five board grades in terms of usage. On board grade 170T2/155C/170T2, Corruusual board performance (between 2017 to 2022) decline is mostly evident from 2020 on both ECT and FCT, also decrease by 38% and 14% on ECT and FCT respectively when year 2017 and year 2022 are compared as shown in Figure 10 (a) below. Everest board performance (between 2020 to 2022) decline is mostly evident in year 2022 on both ECT and FCT and also decrease by 24% and 22% on ECT and FCT respectively when year 2020 and year 2022 are compared, as shown in Figure 10(b) below.

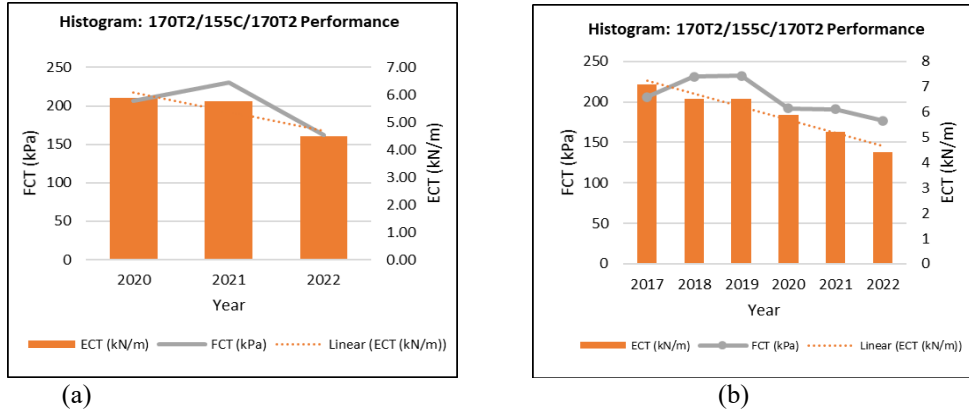


Figure 10. Histogram of ECT and FCT results for Corruveal (a) and Everest (b) for 170T2/155C/170T2

On board grade 140T2/120C/100FL, Corruveal board performance (between 2017 to 2022) decline is mostly from 2021 on ECT and 2022 on FCT, also decrease by 31% and 25% on ECT and FCT respectively when year 2017 and year 2022 are compared as shown in Figure 11 (a) below. Everest board performance (between 2020 to 2022) decline is mostly evident from year 2021 on both ECT and FCT and decrease by 10% and 14% on ECT and FCT respectively when year 2020 and year 2022 are compared, as shown in Figure 11(b) below.

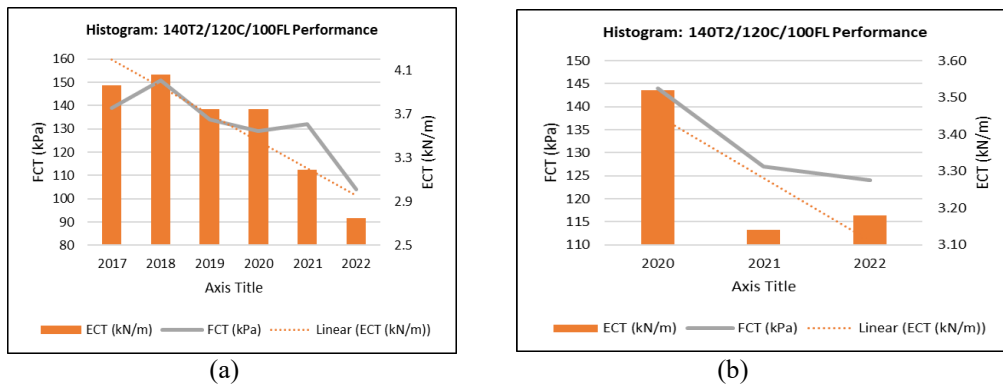


Figure 11. Histogram of ECT and FCT results for Corruveal (a) and Everest (b) for 140T2/120C/100FL

On board grade 140T2/120B/120FL, Corruveal board performance (between 2017 to 2022) decline is mostly from 2021 on ECT and 2022 on FCT, also decrease by 31% and 21% on ECT and FCT respectively when year 2017 and year 2022 are compared as shown in Figure 12 (a) below. Everest board performance (between 2020 to 2022) decline is mostly evident from 2021 on both ECT and FCT and decrease by decrease by 14% and 20% on ECT and FCT respectively when year 2020 and year 2022 are compared, as shown in Figure 12 (b) below.

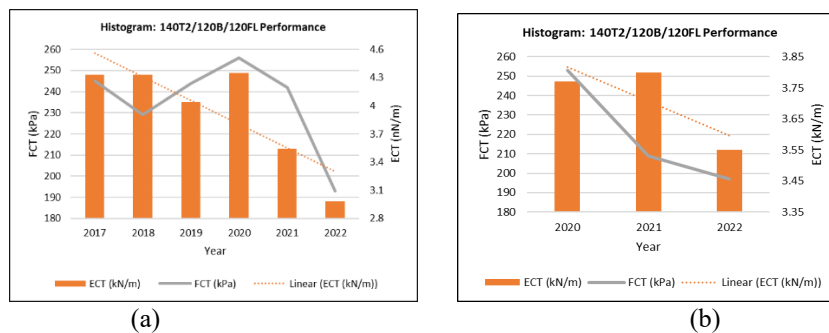


Figure 12. Histogram of ECT and FCT results for Corruveal (a) and Everest (b) for 140T2/120B/120FL

On board grade 140T2/155C/140T2, Corruveal board performance (between 2017 to 2022) decline is mostly from 2021 on ECT and 2022 on FCT, also decrease by 31% and 21% on ECT and FCT respectively when year 2017 and year 2022 are compared as shown in Figure 13 (a) below. Everest board performance (between 2020 to 2022) decline is mostly evident from 2021 on both ECT and FCT and decrease by 14% and 20% on ECT and FCT respectively when year 2020 and year 2022 are compared, as shown in Figure 13(b) below

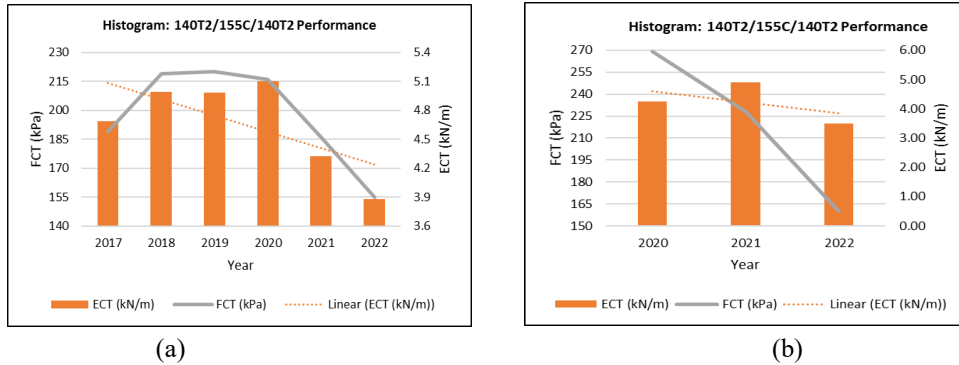


Figure 13. Histogram of ECT and FCT results for Corruveal (a) and Everest (b) for 140T2/155C/140T2

On board grade 140T2/120C/120FL, Corruveal board performance (between 2019 to 2022) decline is mostly from 2020 on ECT on FCT, also decrease by 26% and 16% on ECT and FCT respectively when year 2017 and year 2022 are compared as shown in Figure 14 (a) below. Everest board performance (between 2020 to 2022) decline is mostly evident from 2022 on both ECT and FCT and decrease by 14% and 20% on ECT and FCT respectively when year 2020 and year 2022 are compared, as shown in Figure 14(b) below.

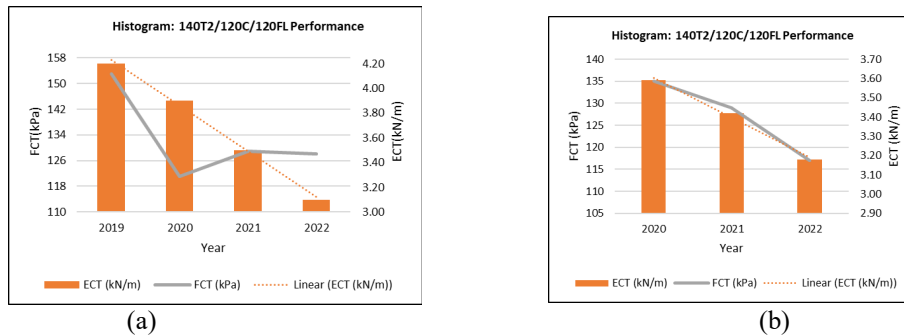


Figure 14. Histogram of ECT and FCT results for Corruveal (a) and Everest (b) for 140T2/120C/120FL

4.2. Suppliers' performance: Corruveal versus Everest

Research objective 2 dealt with checking if the materials performance on ECT and FCT variables between the two suppliers (Corruveal and Everest), is the same. On ECT, as it can be seen on table 4.6 above and Figure 15 below, Everest is performing better on ECT by big margin (10% and 12% higher on 170T2/155C/170T2 and 140T2/155C/140T2 board grades respectively) on two of the board grades while the rest of the board grade is on par.

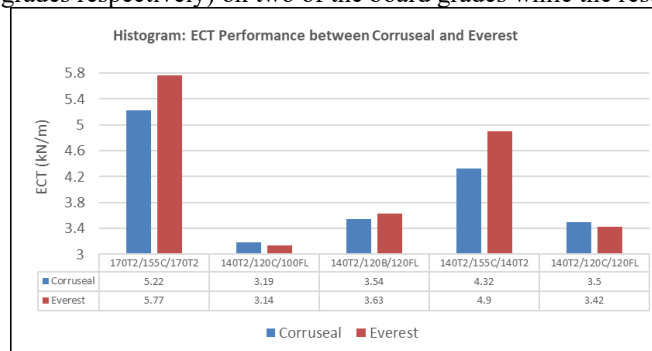


Figure 15. Histogram of ECT results for Corruveal and Everest

On FCT, as it can be seen on Figure 16 below, Everest seems to be performing better on ECT by big margin (17% and 18% higher on 170T2/155C/170T2 and 140T2/155C/140T2 board grades respectively) on two of the board grades while Corruaseal is performing better 140T2/120B/120FL by 14%, and the rest of the board grade seems to be on par.

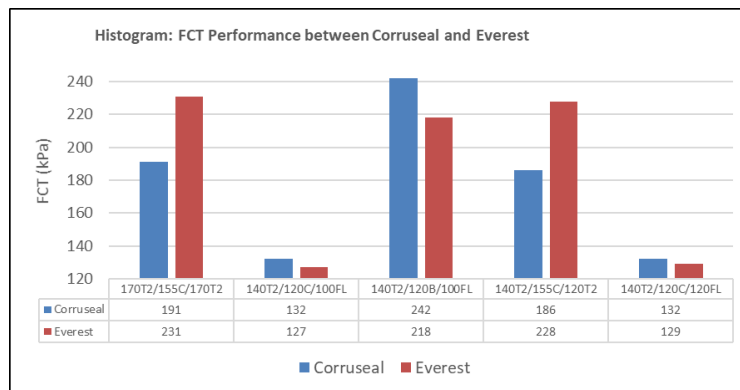


Figure 16. Histogram of FCT results for Corruaseal and Everest

4.3. Machine folding settings vs. box compression strength

As it was explained above that 80% strength of corrugated boxes is derived from the corners. Since that the case, tests were made to check if crushing corners at a less magnitude will increase the strength of corrugated corners. At the same time, if boxes are crushed less, will it affect the process capability of folding gaps and fishtailing variables. To get the proper folding (folding gaps and fishtailing) the following setting must be adhered to:

- the general guideline for setting the nip of the pre-creaser is Board caliper x 0,5 (1/2 of board caliper), and
- the crease impression should be set to board caliper x 0,25 (1/4 of Board caliper)

Both above settings were adhered to, and as part of the experiment, the following settings were also done to see if BCT can be increased without affecting process capability of the folding parameters

- setting the nip of the pre-creaser at Board caliper x 0,75 (3/4 of board caliper), and
- the crease impression was set to board caliper x 0,5 (1/2 of Board caliper)

Results are shown at table 4.1 below and are summarized as follows:

- While Cpk values for both setting remains under 1 (which shows process is not capable), Cpk values of current setting are closer to 1 while Cpk value of experimental setting is very low.
- Cpk value is reduced by 72%, 63% and 58% on lead gap, trail gap and fishtailing when comparing current settings and experimental settings of folding, as shown below on Table 1(a)
- BCT value is only increased by 4% when comparing current settings and experimental settings as shown in Table 1(b) below

In conclusion it is not worth changing folding setting as Cpk is affected by big margins and BCT is increased by a small margin.

Table 1. Folding setting Cpk results (a) and BCT results (b)for current and experimental settings

Cpk			
Settings	Lead Gap	Trail Gap	Fishtailing
Current	0.93	0.85	0.61
Experiment	0.26	0.31	0.26
% Difference	72	63	58

(a)

BCT	
Current Setting	339
Experiment	352
% Difference	4

(b)

It was also found that theoretical calculation using Mckee formula underestimates the BCT requirement as compared to actual BCT as seen below on table 4.2 and Appendix K below. It was seen that it can underestimate by as much as 33%.

Table 2. Actual BCT vs Theoretical BCT

Actual BCT(kgf)	Theoretical BCT*(kgf)	% BCT Difference
490	456	7
134	118	12
359	256	29
251	167	33
235	172	27
641	667	-4
456	397	13
138	138	0
410	435	-6
208	158	24
412	454	-10

4.4. Straight creases design versus offset creases design

This was done on check if box design of the same dimension is changed, and BCT results of both designs are checked. This was done on the box where the customer has recently raised the collapsing complaint. The two designs share same board grade and dimensions. The new design had offset creases prompted by the new box erecting machine acquired by the customer. The average BCT results are shown below on Table 3 and appendix m below. The results show that changing to offset creases reduced BCT by 45%

Table 3. BCT for old and new design

Design	BCT (kgf)
Straight Creases	495
Offset Creases	270

4.4. Summary Of Key Findings

Key findings were summarized as follow:

- Raw materials performance has seen a decline when 2022 is compared to other years for both suppliers on both ECT and FCT results
- On majority of the board grade, Everest was seen as performing better by big margins when compared to Corruveal
- Changing machine folding settings (pre-creasers and creasers) will not improve the BCT results but will only affect folding process capability negatively.

- At design stage, customer requirements on stacking strength are rarely assessed, which can cause collapsing issues at a later stage due to such requirements not being met or when the customer changes their stacking requirements to reduce shipping costs
- Changes in design, such as changing to offset creases can significantly affect stacking strength and as a result may cause collapsing issues.

6. Conclusion and recommendations

The following are conclusions and recommendations based on the key findings mentioned above:

- Since raw materials performance is on decline, XYZ Boxing must work with the supplier to address such issue. This can be done by meeting on a monthly basis to review the performance of most five used board grades and requesting the supplier to come up with corrective action to address the performance issues
- One supplier seems to be performing better than the other, XYZ Boxing can choose which board grades to acquire from which supplier based on the performance of raw materials
- Since changing folding settings does not bring improvement in BCT, settings should stay the same as the process capability was seen as better at current settings when compared to experimental settings.
- XYZ Boxing should introduce customer requirements at design stage based on stacking practices by the customer for each new product to ensure that such requirements are known and met before even supplying the products. This will eliminate address issues of collapsing with the initial order and address issue of collapsing where the customer changes stacking practices to save shipping costs. One tool that can be used is QFD.
- When design changes are implemented, performance of the new design should be tested through entire supply chain to verify that new design will perform at the same level if not better when compared to the old design.

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